

## Study 2.6 Operations Analysis Mission Characterization

Prepared by Advanced Vehicle Systems Directorate  
Systems Planning Division

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STUDY 2.6 OPERATIONS ANALYSIS: MISSION CHARACTERIZATION

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## 1. INTRODUCTION

Study 2.6, Operations Analysis, has as its primary objective the analysis of the current operations concepts of NASA and DoD to determine if alternatives exist which may improve the utilization of resources. In addition, ground rules and assumptions used in previous studies will be reexamined for application to this study. Wherever questions arise concerning these variables, a parametric assessment will be performed. The final product is intended to show how sensitive these ground rules and design approaches are relative to the total cost of doing business. The results will be primarily comparative in nature, assessing one concept against another as opposed to establishing an absolute cost value for program requirements.

This report provides the first step in this process, an assessment of the mission characteristics as identified in the Statement of Work and Study Plan, Refs. 1 and 2. However, in an effort to improve communications with the NASA Task Monitor and other representatives, this report has been expanded to cover an additional objective: to clarify the intent, scope, and direction of this effort to improve the understanding of what is to be accomplished.

In attempting to characterize the various missions of interest, it has been helpful to review other contractor study results. Previous approaches employed have grouped the missions such that one mission can represent all the design drivers of the several missions within that group. However, this approach is design oriented and tends to obscure the uncertainties involved in overall operational considerations. Therefore, the characterization of missions for this study is oriented toward grouping missions which may offer potential economic benefits by reducing overall program costs. Program costs, within this context, include Design, Development, Testing, and Engineering (DDT&E), recurring unit costs for logistic vehicles, payload costs, and direct operating costs. If, for instance, the missions can be grouped to take advantage of multiple payload

deployment or servicing, the flight rate may be reduced, affording a drop in direct operating costs. This then represents a savings in available resources.

Since the interest lies in utilization of resources, consideration must be given to the compatibility of mission operations, compatibility of coupling payloads together, and the capability of the logistic vehicles to perform multiple payload operations. Studies to date have to some degree employed multiple payload loadings in the Shuttle or on the Tug somewhat arbitrarily. This may be acceptable in a gross sense, but further study is required to assure the results incorporate such items as support structure, phasing requirements for deployment and servicing, and the compatibility of multiple payloads on any flight.

Finally, one more point of importance is the uncertainties associated with the mission and vehicle definitions. These uncertainties may lead to either optimistic or overly conservative estimates of resource expenditures. Therefore, a portion of each section on characteristics has been devoted to identifying the variations in the basic data which may affect the final analysis. The sensitivity of the results to these uncertainties will be assessed later in the study effort as described in the Study Approach, Section 7.

## 2. BASELINE OPERATIONAL CONCEPT

It is helpful for reference purposes to define the foundation from which this study has been initiated. This is not intended to represent any firm operational concept accepted by NASA or DoD but rather one which appears to be reasonably well understood such that alternatives may be compared with it. Neither is it intended to represent a complete definition of all aspects of the operational requirements, since many of these requirements may be management oriented and may not affect the economics of operations. The NASA Study 2.1 (Ref. 3) performed by Aerospace in FY 1972 is the basis for much of this information, in that that study has received wide distribution.

The fundamental mission model to be used for Study 2.6 is the 1971 baseline mission model Case 403 Best Mix. This mix of payloads was developed under Study 2.0 (Ref. 3) and is summarized in Appendix A. This study was subsequently expanded to examine the sensitivity of Shuttle operations to variations in the mission model. One series of excursions analyzed (Ref. 5), resulted in another payload best mix definition, identified as Case 506. This case is summarized in Appendix B. The results of both cases are discussed in this report to show the influence of mission model variations on operational considerations.

The Shuttle serves as the basic transport vehicle from earth surface to low earth orbit. The Shuttle definition is provided by the JSC Internal Note No. 71-FM-350, dated May 16, 1972 (Ref. 5). The performance capability appears to be somewhat optimistic at this point in time, especially for polar launches. The Shuttle is assumed to be operational at NASA's Kennedy Space Center in 1979 and at the Air Force's Western Test Range in 1980. Phaseover from expendable launch vehicle is as defined by the Case 403 and Case 506 basic data.

The Shuttle is assumed to have an on-orbit stay capability of seven days. Multiple payloads may be carried in the payload bay along with an upper stage, if necessary. In Case 403 it is assumed that, where necessary,

payloads transported in one Shuttle may be mated in orbit with a Tug transported in a second Shuttle. The same consideration holds for tandem Tugs. This appears questionable within the seven-day time period. Consequently, in Case 506, Tug/payload combinations were fixed from lift-off for the entire flight. In general, the Shuttle was to its full capacity, resulting in off-loading of Tug propellants. Interface structure penalties were not included in these two cases due to the uncertainty at that time.

Once the Shuttle is on-orbit, the upper stage is deployed. The baseline Tug, defined in Ref. 7, has been used with minor modifications provided by Telecon from Marshall Space Flight Center. The Tug has a dry weight of 2,369 kg (5,223 lb) and a full propellant load of 25,400 kg (56,000 lb). Other stages (Agena, Centaur) were employed by a priori assignment consistent with the 403 "best mix" definition. The Tug can be deployed from both the Eastern Test Range and the Western Test Range. When used at WTR, the maximum propellant load is 12,200 kg (26,926 lb). The velocity requirements do not fully account for phasing maneuvers and, hence, are somewhat optimistic. Velocity requirements were subsequently developed and are presented in Section 5.

The payload definitions from the 403 "best mix" include current expendable, current reusable, low cost expendable, and low cost reusable designs. These definitions include mounting structure provisions as required on the payload side of the interface. It is assumed that all payloads are compatible for multiple launch within the Shuttle or on the Tug. A preliminary analysis performed as a part of this study was unable to identify any significant reason to preclude multiple operations except, possibly, for planetary missions. It has been assumed that all payloads to be launched in a given year are available at the beginning of that year to be scheduled as necessary to minimize the launch rate. There are exceptions, however, where a particular application calls for the same payload to be launched several times for short orbital periods within a given year to gather information over the full time period. In this event, multiple loading of the

same payload on a single Shuttle was disallowed. As will be shown in Section 3, this results in poor load factors in some instances.

These represent the fundamental definitions associated with the missions to be discussed in Section 3. There is no requirement to include fleet size or turnaround time in the current effort, because the recurring investment has been amortized in the operational flight costs. These factors will be included later in the analysis to bring in the full utilization of resources.

### 3. MISSION CHARACTERIZATION

A preliminary assessment of the NASA and non-NASA missions has been performed to develop an understanding of those factors influencing the overall flight rate. The results presented are based upon an analysis of the 1971 mission model and the 403 "best mix" traffic definition developed under Study 2.1. Although excursions of this model have been developed, the 1971 mission model still represents the baseline. By contrast, the 1972 excursion is also analyzed and the results compared with the 1971 baseline.

The results provided were developed using the DORCA II (Dynamic Operational Requirements and Cost Analysis) computer program. As has often been pointed out, this program does not provide an optimum loading of payloads on logistic vehicles but does allow an iterative solution satisfactory for comparative analyses. Considering the uncertainties involved in long range planning, this is acceptable for the present effort. The following questions were addressed:

What load factor was achieved for each operational leg?

To what extent were multiple payload operations employed?

What potential exists for improving the efficiency of the flight operations?

What uncertainties exist which may alter the derived results?

The overall flight schedule is provided in Table 3-1. This table shows the total number of flights for each vehicle employed as well as the yearly distribution. There are several cases where "off-loaded" Tugs are employed. These represent a priori assignments because of the unique nature of a given mission, where it is known from previous work that a full propellant load is not required to perform the missions. Therefore, reducing the propellant load reduces the requirement on the lower legs; i.e., the Shuttle "up" load. This allows additional payloads to be installed in the Shuttle payload bay on the same flight and maintains a reasonable degree of agreement with Study 2.1, which serves as a point of departure. In Case

Table 3-1. Vehicle Flight Summary - Case 403

VEHICLE	YEARLY FLIGHTS																				TOTAL
	79	80					85					90					95				
SHUTTLE	10	23	34	25	31	28	32	29	32	29	33	25	34	22	33	25	26	23	26	520	
TUG-BASELINE	6	12	17	9	13	12	10	12	15	12	11	9	15	10	14	11	11	10	14	223	
OFF-LOAD TUG	2	1	2	1	2	1	2	0	2	2	2	1	2	1	2	1	2	0	2	28	
TUG-WTR	0	4	2	5	2	4	3	4	2	4	3	4	1	4	1	3	1	3	1	51	
TANDEM TUG	0	0	1	1	1	2	1	1	0	1	1	0	2	0	1	2	1	1	0	16	
TITAN IIC	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	
T-IIIB/AGENA	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	
TAT 3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
T-IIIF/CENTAUR	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
CENTAUR	0	0	0	2	0	0	1	0	0	1	0	4	0	0	2	0	0	1	2	13	
T-IIIF/CENT/B	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
CENT/KICK	0	0	0	0	0	0	1	1	1	0	1	0	0	1	0	0	0	1	0	6	



506 these off-loaded vehicle assignments were performed by the DORCA computer program.

The mission operations associated with the flights totaled in Table 3-1 have been collected into groups having similar inclinations, either on the first leg from earth surface to low earth orbit, or the final leg from earth orbit to the terminal point (mission orbit). Unique missions which do not fall readily into these groups are addressed separately. The leg definitions are defined in Table 3-2. These conditions encompass all the flights that offer some potential for multiple payload operations. It should be noted that the basic data for the Shuttle indicated a payload delivery capability of 4,490 kg (9,900 lb) to a 926 km (500 nmi) orbit with an inclination of 100 degrees. The payloads to be delivered were defined as NEO 2, 2,672 kg (5,890 lb) and NEO 16, 2,894 kg (6,380 lb). Subsequent information has shown the Shuttle to have zero payload capability for this orbit. Consequently, if this model were rerun using the reduced capability, Tug flights would be required for these payloads, increasing the costs slightly; however, the number of Shuttle flights would remain very nearly the same.

A further breakdown of the flight conditions is provided in Tables 3-3 through 3-11 showing the distribution of payloads for each flight. Table 3-3 shows that 40 Shuttle flights were performed on this leg with only one payload up and one payload down. This includes delivery of Tugs as required. The majority of flights (99) carried two payloads up and two payloads down. Over the total number of 331 flights for this leg, the average load factor was 80%. This is considered to be favorable and further improvement is questionable. A detailed look at the payload combinations may afford a savings of two or three flights but this would probably not alter the average load factor significantly.

Of the 331 flights of the Shuttle going to earth orbit, 191 are scheduled for subsequent Tug flights to synchronous equatorial orbit. The payload distribution on the Tug leg is shown in Table 3-4. The majority of flights have one payload scheduled up and one payload down for an average load factor of 67%. However, a detailed look at each case shows several flights with a load factor of 10%, indicating poor scheduling. This also

Table 3-2. Logistic Vehicle Operational Legs\*

INCLINATION (Degrees)			APPLICABLE VEHICLE	MISSION ORBIT CHARACTERISTICS			
No.	1st Leg	2nd Leg		h <sub>a</sub> km (nmi)		h <sub>p</sub> km (nmi)	
1.0	28.5	---	Shuttle	185	(100)**	185	(100)
1.1		0	Tug	35,786	(19,323)	35,786	(19,323)
1.2		28.5	Tug	55,560	(30,000)	29,630	(16,000)
1.3		28.5	Tug	3,333	(1,800)	333	(180)
1.4		28.5	Tug	37,040	(20,000)	1,850	(1,000)
2.0	28.5	---	Shuttle	648	(350)	648	(350)
3.0	90	---	Shuttle	185	(100)	185	(100)
3.1		90	Tug	3,333	(1,800)	333	(180)
3.2		90	Tug	5,556	(3,000)	556	(300)
3.3		90	Tug	37,040	(20,000)	1,850	(1,000)
4.0	90	---	Shuttle	741	(400)	741	(400)
5.0	100	---	Shuttle	185	(100)	185	(100)
5.1		100	Tug	1,296	(700)	1,296	(700)
6.0	100	---	Shuttle	926	(500)***	926	(500)

\* Additional Unique Legs in Table 3-11

\*\* Tug Performance Based Upon 160 nmi orbit

\*\*\* Subsequent Data Indicated Zero Payload Capability

Table 3-3. Payload Distribution of Shuttle Flights  
into 100 nmi Orbit ( $i = 28.5^\circ$ )

$h_a = h_p = 185 \text{ km (100 nmi)}$ ; Average Load Factor: 80%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	---	2	32	11	3	---
	1	---	40	29	7	7	---
	2	---	40	99	26	3	---
	3	---	---	26	3	---	---
	4	---	---	2	1	---	---
	5	---	---	---	---	---	---

TOTAL FLIGHTS THIS LEG: 331

Table 3-4. Payload Distribution of Tug Flights  
into Synchronous Equatorial Orbit ( $i = 0^\circ$ )

$h_a = h_p = 35,786 \text{ km (19,323 nmi)}$ ; Average Load Factor: 67%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	---	23	6	1	---	---
	1	11	89	22	7	---	---
	2	---	15	12	2	---	---
	3	---	2	1	---	---	---
	4	---	---	---	---	---	---
	5	---	---	---	---	---	---

NOTE: 10 Additional tandem Tug  
flights deployed and  
retrieved; one payload

TOTAL FLIGHTS THIS LEG:

191

indicates that excess Tug performance exists on numerous flights. Specifically, approximately 40 flights have a load factor less than 30%. Consequently, the missions covered in this group have a good potential for improvement either in improved multiple payload missions or for simultaneous on-orbit servicing. Further analysis will be required to determine if an adjustment in individual flight schedules could improve the overall operation. In addition, the ten tandem Tug flights were dedicated to round trip operations with the payload NCN 1, weighing 4,275 kg (9,424 lb). This payload was dropped from the 1972 excursion; hence, tandem Tug operations were reduced substantially.

In addition to the missions included in Table 3-3 and 3-4, there are 30 flights which originate from the first Shuttle leg at  $28.5^\circ$  inclination to altitudes other than synchronous equatorial. Each of these flights is dedicated to servicing a unique orbit, resulting in poor load factors for the Tug. The navigation satellite NCN 10, weighing 405 kg (893 lb) is launched (and returned) by the Tug into a 55,560 km by 29,630 km (30,000 nmi by 16,000 nmi) orbit. The average Tug load factor is 17%. The low magnetosphere satellite NSP 1A, 2,140 kg (4,718 lb), has ten flights to an 3,333 km by 333 km (1,800 nmi by 180 nmi) orbit for a Tug load factor of 4%. The mid-magnetosphere satellite NSP 2B, 1,223 kg (2,698 lb) has ten flights to a 37,040 km by 1,850 km (20,000 nmi by 1,000 nmi) orbit, with a Tug load factor of 18%. In each case, these payloads are recovered. In spite of the uniqueness of their orbits, it still may be possible to conduct multiple payload operations within the capability of the Tug. The magnetosphere satellites have compatible launch schedules, and preliminary analyses indicate dual deployment is feasible with the baseline Tug. Dual retrieval may also be feasible with proper phasing. Phasing requirements are discussed in detail in Section 5.

Consideration should also be given to changing the mission orbit inclination. If the magnetosphere satellites could be combined with the synchronous equatorial missions, an obvious cost benefit will accrue. Also it appears feasible to launch the navigation satellite (NCN 10 mentioned above) from synchronous equatorial conditions. If these prove out, it may

be possible to reduce the Tug flights by approximately 30 flights. Shuttle flights may not be reduced, because a relatively high load factor has already been achieved.

Table 3-5 examines the Shuttle for missions to a 649 km (350 nmi) circular orbit at 28.5 degrees inclination. For these missions, the average load factor was less than 30%. This has been brought about by two factors: the payload loading is limited by length constraints, and there are numerous revisit flights. The volumetric load factors are shown in Table 3-6. Except for those years when no new payloads are deployed, the volumetric loading is relatively high for the first flight, averaging well above 95% even though the weight load factors are less than 50% for the same flights. The flight efficiency drops significantly for subsequent flights of the same year, since these are primarily revisits. The mission model requires two revisits to each of these payloads each year. The weights associated with the revisits are not greater than 2,722 km (6,000 lb).

Several options may be considered for this group of missions. The first point is to reevaluate the revisit schedule in lieu of the poor load factors. Revisits become very expensive when the Shuttle flight costs cannot be more widely distributed. A single revisit each year may be preferable. This point must be negotiated with the payload Principal Investigator. Another option is to use the Tug for revisit missions and combine the Tug operations with other payload requirements such as the low or mid-magnetosphere experiments. A third course is to reduce the orbital altitude to 296 km (160 nmi) and combine operations with synchronous equatorial missions, using this orbit as the point of departure. The alternative is not altogether promising because a relatively high load factor already exists for Shuttle flights to this altitude.

The next grouping of missions is taken at an inclination of 90 degrees and an altitude of 185 km (100 nmi). Thirty-three flights have been identified with an average load factor of 87%. The distribution of payloads relative to the flights is shown in Table 3-7. Some improvement may be possible when analyzed in detail, however, any substantial improvement is doubtful since this already is a reasonably high load factor. All of these flights service

Table 3-5. Payload Distribution of Shuttle Flights  
into 350 nmi Orbit ( $i = 28.5^\circ$ )

$h_a = h_p = 648 \text{ km (350 nmi)}$ ; Average Load Factor: 28%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	---	3	1	2	---	---
	1	---	6	1	1	---	---
	2	1	1	34	2	---	1
	3	1	1	---	1	2	---
	4	---	---	1	2	1	---
	5	---	---	---	---	---	5

TOTAL FLIGHTS THIS LEG: 67

Table 3-6. Volumetric Load Factors for Shuttle at 648 km (350 nmi)  
Circular Orbit and 28.5 deg Inclination

Flight No.	Year																			Average per Flight
	1979	1980*	1981	1982	1983	1984*	1985	1986*	1987*	1988	1989	1990*	1991	1992	1993	1994	1995	1996	1997	
1	0.970	0.480	0.990	0.970	1.000	0.440	0.990	0.440	0.070	1.000	0.970	0.440	0.990	0.950	1.000	0.950	0.880	0.950	0.990	0.82
2	-	0.220	0.220	0.440	0.440	0.440	0.930	0.440	0.440	0.440	0.440	0.440	0.950	0.950	0.970	0.880	0.660	0.510	0.950	0.59
3	-	-	0.070	0.440	0.440	0.440	0.570	0.440	0.440	0.440	0.440	0.440	0.440	-	0.880	-	0**	-	0.440	0.42
4	-	-	-	-	0.140	0.070	0.570	0.440	0.440	0.440	0.440	0.440	0**	-	0.660	-	-	-	-	0.36
5	-	-	-	-	-	-	0.440	0.140	0.440	0.360	0.440	-	-	-	-	-	-	-	-	0.36
6	-	-	-	-	-	-	0.440	-	-	-	-	-	-	-	-	-	-	-	-	0.44
Total Flights	1	2	3	3	4	4	6	5	5	5	5	4	4	2	4	2	3	2	3	67
Average Volumetric Factor	0.97	0.35	0.43	0.62	0.51	0.35	0.64	0.38	0.37	0.54	0.55	0.44	0.59	0.95	0.88	0.92	0.51	0.73	0.79	0.57

NOTE: Volume Load Factor =  $\frac{\text{Total Length of Payloads}}{\text{Payload Bay Length}}$

\* All flights are revisits to existing satellites; flights restricted to two revisits each flight.

Large Stellar Telescope, NAS-1  
Hi Energy Astronomical Observatory, NAS-4  
Large Stellar Observatory, NAS-2  
Astronomy Explorer, NAS-14  
Large Radio Observatory, NAS-3  
Orbiting Solar Observatory, NAS-15

\*\* Flight required for retrieval; no up payloads assigned.



Table 3-7. Payload Distribution for Shuttle Flights  
into 100 nmi Polar Orbit ( $i = 90^\circ$ )

$h_a = h_p = 185 \text{ km (100 nmi)}$ ; Average Load Factor: 87%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	---	---	---	---	---	---
	1	---	---	1	---	---	---
	2	---	1	31	---	---	---
	3	---	---	---	---	---	---
	4	---	---	---	---	---	---
	5	---	---	---	---	---	---

TOTAL FLIGHTS THIS LEG: 33

the first leg for Tug flights in polar orbit. Fifteen flights are required to deploy/retrieve two navigation satellites (NCN 2B and NCN 3B) in an orbit of 5,556 km (3,000 nmi) apogee by 556 km (300 nmi) perigee. The Tug has excess performance capability; hence, a very low load factor of 4.5% is achieved. This mission may be combined with the low magnetosphere satellite (NSP 1A). This satellite is deployed into an orbit of 3,333 km by 333 km (1,800 by 180 nmi). Nine flights are required over the time period of interest, with a load factor of 8.4%. The mid-magnetosphere satellite (NSP 2B), 37,040 km by 1,850 km (20,000 nmi by 1,000 nmi) may also be a candidate for multiple mission operations. However, its nine flights have a relatively high load factor of 75%. Off-loading the Tug may offer some improvement. Other alternatives such as a smaller Tug, increased satellite lifetime, or combined operations with other payloads must also be considered.

The next set of flights with an inclination of 90 degrees utilizes the Shuttle for deployment into a 741 km (400 nmi) circular orbit. A total of 15 flights have been developed, ten of which have multiple payloads as shown in Table 3-8. The average load factor is 12%, indicating an inefficient operation. It may be possible to perform some further combination of missions with those previously discussed for this inclination. It also appears that a small Tug may offer some advantages, particularly if the requirements are compatible with similar missions from the Kennedy Space Center.

The next set of missions has been grouped around an inclination of 100 degrees. Eighteen Shuttle flights have been loaded to carry NEO 6 and NEO 7 satellites with Tugs to an altitude of 185 km (100 nmi). These two satellites are meteorological satellites destined for a final orbit of 1,296 km (700 nmi) circular. The average Shuttle load factor is 96%, and five of the flights had three payloads on both the up and down legs. The distribution of these flights is shown in Table 3-9. Unfortunately, the average load factor for the Tug is a very low 2%, due to the restricted launch schedule of one NEO 7 satellite per year and one NEO 6 satellite approximately every four years. This also points out that the high Shuttle load factor on the first leg

Table 3-8. Payload Distribution for Shuttle Flights  
into 400 nmi Polar Orbit ( $i = 90^\circ$ )

$h_a = h_p = 741 \text{ km (400 nmi)}$ ; Average Load Factor: 12%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	---	5	---	---	---	---
	1	---	8	---	---	---	---
	2	---	2	---	---	---	---
	3	---	---	---	---	---	---
	4	---	---	---	---	---	---
	5	---	---	---	---	---	---

TOTAL FLIGHTS THIS LEG:

15

Table 3-9. Payload Distribution for Tug Launched from WTR  
into 700 nmi Orbit ( $i = 100^\circ$ )

$h_a = h_p = 1,295 \text{ km (700 nmi)}$ ; Average Load Factor: 2%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	---	---	---	---	---	---
	1	---	13	---	---	---	---
	2	---	---	5 LF = 2.8%	---	---	---
	3	---	---	---	---	---	---
	4	---	---	---	---	---	---
	5	---	---	---	---	---	---

TOTAL FLIGHTS THIS LEG: 18

is misleading in this instance. The Tug loaded into the Shuttle had an excess propellant load (as evidenced by the 2% load factor). The Tug could be off-loaded, thereby improving the Tug leg but lowering the load factor of the Shuttle. In any event, the driving factor is the launch schedule into a unique orbit. Reducing the Tug size would not reduce the number of Shuttle flights.

Two alternatives for these missions are apparent: increase the mean mission duration of the NEO 6 and NEO 7 satellites or combine the satellites with those launched at 90 degrees inclination. The second approach requires a plane change maneuver for the Tug, which is feasible for deployment modes because of the excess performance capability. However, dual retrieval is questionable because the orbit planes separate over a period of time. It may be possible to find a particular point in time when the orbits are sufficiently close to being coplanar that dual retrieval operation can be performed. This is discussed in Section 5. However, it is also desirable for NASA to reevaluate the lifetime requirements of these satellites to determine if improvements are justifiable.

Comparing Table 3-9 with Table 3-10, a third alternative may offer some improvement. The missions of Table 3-10 require Shuttle flights to a 926 km (500 nmi) circular orbit having a 100 degree inclination. Although the table reflects the DORCA results using 1971 mission model/Shuttle data, it should be realized that the latest Shuttle performance figures indicate zero payload capability for this orbit. As an alternative, it may be possible to lower the mission orbit to stay within the performance capability of the Shuttle. Also, these missions may be compatible with those of Table 3-9 so that a single Tug could deploy/retrieve satellites at both altitudes.

The volume constraint of the payload bay must also be considered. The table below indicates the percentage of the 18.3 km (60-ft) length absorbed by each element. The Shuttle could load one Tug, one NEO 6 satellite and one NEO 17 within the constraint. Other combinations are possible, but a maximum of two satellites plus the Tug is the upper limit unless the satellites can be reconfigured.

Table 3-10. Payload Distribution for Shuttle Flights  
into 500 nmi Orbit ( $i = 100^\circ$ )

$h_a = h_p = 926 \text{ km (500 nmi)}$ ; Average Load Factor: 62%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	---	15	---	---	---	---
	1	---	41	---	---	---	---
	2	---	---	---	---	---	---
	3	---	---	---	---	---	---
	4	---	---	---	---	---	---
	5	---	---	---	---	---	---

TOTAL FLIGHTS THIS LEG: 56

PAYLOADS	ALTITUDE KM (NMI)	WEIGHT KG (LB)	LENGTH % OF 18.3 KM
NEO 2 LCR	926 (500)	2,713 (5,980)	28
NEO 16 LCR	926 (500)	2,894 (6,380)	27
NEO 17 LCE	926 (500)	2,576 (5,680)	22
NEO 7 CR	1,296 (700)	564 (1,244)	12
NEO 6 CR	1,296 (700)	564 (1,244)	18
TUG		14,583 (32,148)	58

All of the missions discussed above have some potential for multiple payload operations, thereby reducing the overall program costs. There are, however, a set of missions which are unique as currently defined and offer little potential for improvement. These are listed in Table 3-11 for reference purposes. Where only the final leg is unique, (i. e., planetary missions) the payloads may have been combined on a lower leg. Wherever Tug flights are involved, the Tug is recovered and transported as a Shuttle down leg. Wherever tandem Tugs are required, the upper stage is expended. Except for those noted, these missions exist as single flights with, in general, a high load factor. Consequently, any alteration to the basic operational concept will have little effect on these missions.

Table 3-11. Unique Missions

Mission Payload	Logistics Vehicle	Mission Orbit			Characteristic Velocity, mps (fps)	Total No. Flights	Average Load Factor, Percent
		i, deg	ha, km (nmi)	hp, km (nmi)			
NAS 11-CE *	Tug	28.5	71,572 (38,646)	71,572 (38,646)	-	2	69
NSP 3-LCE	Tug	28.5	1 a.u.	1 a.u.	-	16	16
NSP 7-LCE							
NAS 8-CE							
NAS 7-CE*	Tug	30	35,786 (19,323)	35,786 (19,323)	-	3	10
NAS 9-CE*	Tug	30	35,786 (19,323)	35,786 (19,323)	-	1	40
NAS 10-CE							
NPL 1-CE	Tug		Planetary		12,200 (40,000)	2	71
NPL 6-CE	Tug		Planetary		11,900 (39,000)	3	38
NPL 15-CE	Tandem Tug		Planetary		12,900 (42,322)	2	10
NPL 18-CE	Tandem Tug		Planetary		12,900 (42,322)	4	10
NPL 7-LCE	Centaur		Planetary		11,900 (39,000)	1	55
NPL 8-LCE	Centaur		Planetary		11,900 (39,000)	2	55
NPL 11-CE	Centaur		Planetary		15,700 (51,500)	4	89
NPL 13-CE	Centaur / Kick		Planetary		15,700 (51,500)	3	63
NPL 14-CE	Centaur / Kick		Planetary		16,300 (53,500)	3	79
NPL 19-CE	Centaur		Planetary		12,200 (40,000)	3	90
NPL 20-CE	Centaur		Planetary		12,200 (40,000)	3	90
NEO 16-LCR	THI-B / Agena	100	926 (500)	926 (500)	-	4	99
NEO 2-LCR	THI-B / Agena	100	926 (500)	926 (500)	-	1	93
NCN 11-CE	THI-C	0	35,786 (19,323)	35,786 (19,323)	-	2	81
NCN 7-CR	THI-C		35,786 (19,323)	35,786 (19,323)	-	2	69
NCN 2A-LCR	THI-C	0	35,786 (19,323)	35,786 (19,323)	-	1	50
NEO 15-CR	THI-C	0	35,786 (19,323)	35,786 (19,323)	-	1	49
NCN 2B-LCR	TAT3	90	5,556 (3,000)	556 (300)	-	1	80
NEO 7-CR	TAT 3	100	1,296 (700)	1,296 (700)	-	1	59
NPL 1-CE	THI-F / Centaur		Planetary		12,200 (40,000)	1	68
NPL 10-CE	THI-F / Centaur B2		Planetary		15,700 (51,500)	2	41

\*Potential candidates to be combined with other payloads.



#### 4. CASE 506 MISSION MODEL EXCURSION

A procedure similar to the analysis of the 1972 baseline mission model and Case 403 Best Mix was employed to analyze an excursion to the 1971 mission model which was developed in 1972. Several changes in the 1971 baseline model were incorporated to determine the influence on flight rate and other programmatic factors. Specifically, there was an increase in sortie and space station operations and a reduction in certain payload weight and volume factors. The intent here is not to dwell on all the changes, which are documented in Appendixes A and B, but to determine whether any significant changes in the basic character of operations accrued from the excursions. If the operations are sufficiently similar (that is, use of multiple payloads) then subsequent trade studies are not likely to be impacted by future mission model variations. Case 506 was developed as a part of Study 2.1 performed by Aerospace in FY 1973 and is the basis for evaluating the 1972 excursion.

Table 4-1 defines the operational legs and the logistic vehicle assignments. The vehicle capabilities are essentially the same as used in Case 403 of the 1971 baseline mission model. Planetary missions have been included merely for reference; the remainder of the mission legs are very similar to Case 403. Tables 4-2 through 4-18 tabulate the degree to which multiple payload operations were employed, including those missions employing Centaur or Agena upper stages. All of the Shuttle flights to a circular orbit of  $28.5^{\circ}$  inclination and 296 km (160 nmi) altitude (Table 4-2) carried an upper stage in the cargo bay. The majority of these were Tugs, including those required for tandem Tug flights. This drives the average load factor for the Shuttle up to 90 and 95% in many cases, with an overall average of 79%. The total weight carried into orbit by the Shuttle on this leg is 5,579,000 kg (12,300,000 lb) over a 19-year period for an average of 293,500 kg (647,000 lb) per year. The required upper stages account for 94% of this weight carried into orbit. Automated payloads for the same time period amount to 358,300 kg (790,000 lb) or, on the average 1,497 kg (3,300 lb) per Shuttle flight. This emphasizes the importance of optimizing

Table 4-1. Case 506 Logistic Vehicle Operational Legs

INCLINATION (Degrees)			APPLICABLE VEHICLE	MISSION ORBIT CHARACTERISTICS			
No.	1st Leg	2nd Leg		$h_a$ km (nmi)		$h_p$ km (nmi)	
1.0	28.5	----	Shuttle	296	(160)	296	(160)
1.1		0	Tug	35,786	(19,323)	35,786	(19,323)
1.2		5	Tug	35,786	(19,323)	35,786	(19,323)
1.3		28.0	Tug	34,786	(19,323)	35,786	(19,323)
1.4		28.5	Tug	55,560	(30,000)	29,630	(16,000)
1.5		28.5	Tug	71,572	(38,646)	71,572	(38,646)
1.6		P	Tug	Planetary		VC = 11,130mps (36,500)fps	
1.7		P	Tug			11,550 mps (37,900)fps	
1.8		P	Tug			11,765 mps (38,600)fps	
1.9		P	Tug			12,200 mps (40,000)fps	
1.10		P	Centaur			12,800 mps (42,000)fps	
1.11		P	Centaur			12,900 mps (42,300)fps	
1.12		P	Centaur/B2			13,411 mps (44,000)fps	
1.13		P	Centaur/B2			14,386 mps (47,200)fps	
1.14		P	Centaur			14,570 mps (47,800)fps	
1.15		P	Centaur			14,720 mps (48,300)fps	
1.16		P	Centaur/B2			15,060 mps (49,400)fps	
1.17		P	Centaur			15,210 mps (49,900)fps	
1.18		P	Centaur/B2			15,620 mps (51,250)fps	
1.19		P	Centaur/B2			16,610 mps (54,500)fps	

Table 4-1. Case 506 Logistic Vehicle Operational Legs (Continued)

INCLINATION (Degrees)			APPLICABLE VEHICLE	MISSION ORBIT CHARACTERISTICS			
No.	1st Leg	2nd Leg		km <sup>h<sub>a</sub></sup>	(nmi)	km <sup>h<sub>p</sub></sup>	(nmi)
2.0	28.5	----	Shuttle	463	(250)	463	(250)
3.0	28.5	----	Shuttle	556	(300)	556	(300)
4.0	28.5	----	Shuttle	741	(400)	741	(400)
5.0	55.0	----	Shuttle	500	(270)	500	(270)
6.0	55.0	----	Shuttle	296	(160)	296	(160)
6.1		55	Tug	12,780	(6,900)	12,780	(6,900)
7.0	90.0	----	Shuttle	296	(160)	296	(160)
7.1		90	WTR Tug	3,333	(1,800)	333	(180)
7.2		90	WTR Tug	5,556	(3,000)	556	(300)
7.3		90	WTR Tug	37,040	(20,000)	1,852	(1,000)
8.0	90.0	----	Shuttle	500	(270)	500	(270)
9.0	90.0	----	Shuttle	926	(500)	926	(500)
10.0	100	----	Shuttle	296	(160)	296	(160)
10.1		100	WTR Tug	926	(500)	926	(500)
10.2		100	WTR Tug	1,296	(700)	1,296	(700)
1.03		100	Expendable	1,667	(900)	1,667	(900)
11.0	100	----	Shuttle	926	(500)	926	(500)

Note: 18 expendable launch vehicle legs not included

Table 4-2. Payload Distribution for Shuttle Flights  
into 160 nmi Orbit ( $i = 28.5^\circ$ )

$h_a = h_p = 296$  km (160 nmi); Average Load Factor: 79%  
Average Volume Factor: 84%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	—	28	27	2	—
	1	—	5*	31	13	—	—
	2	—	20	71	34	—	—
	3	—	4	2	3	—	—
	4	—	—	—	—	—	—

\* LOWER STAGE OF TANDEM TUG

\*\* 147 FLIGHTS SUPPORT TUG OPS

TOTAL FLIGHTS THIS LEG 240 \*\*

PERCENT OF TOTAL 42.7%

the upper stage and payload delivery requirements to improve the ratio of actual payload carried to that of upper stages and propellants. It should also be noted that on each Shuttle flight the upper stage was off-loaded of excess propellant beyond what the final mission leg required to allow multiple payload operations wherever possible.

Table 4-2 includes the Tug as a payload so that the majority of Shuttle flights due east carried only one satellite up and one satellite down. This effect is due primarily to the weight constraints of the Shuttle bay rather than volume, although there are a few cases where volume limits did predominate. These results indicate that the payload support structure in combination with the Tug should be designed to be capable of accommodating up to three payloads on the up and down legs. If longshoring were allowed, the efficiency could be improved. Longshoring allows one Shuttle to transport a Tug and payload to orbit and rendezvous with a second Shuttle loaded with payloads. The payloads are then "longshored" onto the Tug for synchronous deployment.

Table 4-3 indicates the efficiency of Tug operations to synchronous equatorial orbit. Approximately 50% of the flights carried only one payload up and one payload down. One third of the flights accommodated multiple payloads. The average load factor is at an acceptable level (82%); however, it should be recognized that this is based upon a weight-constrained off-loaded Tug. If the full Tug capability were employed, the results could change substantially. The volume factor refers to a length of 7.62 m (25 ft) which is the remaining length in the Shuttle after inserting the Tug. This shows that although a few cases of volume limiting did occur, on the average volume constraints are not a limiting factor. Once the Tug became operational (1983), the preponderance of flights to synchronous orbit were service flights\* (70%). The remainder of flights were equally distributed between deployment and retrieval.

The remainder of Tables 4-2 through 4-18 provide the same type of data for other mission orbits. Table 4-4 shows the results of using tandem Tug operations. These were required on five flights to retrieve the NE2-39 in the Low Cost Reusable design configuration 2,511 kg (5,536 lb). Had the

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\*Payloads deployed and retrieved.

Table 4-3. Payload Distribution for Tug Flights  
into Synchronous Equatorial Orbit ( $i = 0^\circ$ )

$h_a = h_p = 25,786$  km (19,232 nmi); Average Load Factor: 82%  
Average Volume Factor: 65%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	6	21	—	—	—
	1	19	61	25	—	—	—
	2	4	1	—	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

TOTAL FLIGHTS THIS LEG 137

PERCENT OF TOTAL 75.3%

Table 4-4. Payload Distribution for Tandem Tug Flights  
into Synchronous Equatorial Orbit ( $i = 0^\circ$ )

$h_a = h_p = 35,786 \text{ km (19,323 nmi)}$ ; Average Load Factor: 86%

Average Volume Factor: 95%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	—	—	—	—	—
	1	—	—	—	—	—	—
	2	—	—	5	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

PRIMARY FACTOR IS RETRIEVAL OF  
NE2-39LCR (5536 LB). BASIC SATELLITE  
WEIGHT (2600 LB) IS COMPATIBLE WITH  
SINGLE TUG. WILL NOT IMPACT SHUTTLE  
FLIGHTS.

TOTAL FLIGHTS THIS LEG 5

PERCENT OF TOTAL 100%

Table 4-5. Payload Distribution for Agena Flights  
into Synchronous Equatorial Orbit ( $i = 0^\circ$ )

$h_a = h_p = 25,786 \text{ km (19,323 nmi)}$ ; Average Load Factor: 85%  
Average Volume Factor: 26%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	2	—	—	—	—
	1	—	—	—	—	—	—
	2	—	—	—	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

TOTAL FLIGHTS THIS LEG 2

PERCENT OF TOTAL 66.7%



Table 4-6. Payload Distribution for Centaur Flights  
into Synchronous Equatorial Orbit ( $i = 0^\circ$ )

$h_a = h_p = 35,786 \text{ km (19,323 nmi)}$ ; Average Load Factor: 40%  
Average Volume Factor: 79%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	8	8	2	—	—
	1	—	—	—	—	—	—
	2	—	—	—	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

TOTAL FLIGHTS THIS LEG 18

PERCENT OF TOTAL 50%

Table 4-7. Payload Distribution for Shuttle Flights  
into 250 nmi Orbit ( $i = 28.5^\circ$ )

$h_a = h_p = 463 \text{ km (250 nmi)}$ ; Average Load Factor: 39%  
Average Volume Factor: 69%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	—	—	—	—	—
	1	—	8	—	—	—	—
	2	—	—	5	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

FLIGHT SCHEDULE CALLS FOR ONE  
FLIGHT PER YEAR = SORTIES MODULES  
COMBINED WHERE POSSIBLE.

TOTAL FLIGHTS THIS LEG 13

PERCENT OF TOTAL 2.3%

Table 4-8. Payload Distribution for Shuttle Flights  
into 300 nmi Orbit ( $i = 28.5^\circ$ )

$h_a = h_p = 556 \text{ km (300 nmi)}$ ; Average Load Factor: 22%  
Average Volume Factor: 51%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	2	—	—	—	—
	1	—	11	3	1	—	—
	2	—	—	28	—	—	—
	3	—	—	—	2	—	—
	4	—	—	—	—	—	—

VOLUME CONSTRAINT IS MAJOR LIMITING  
FACTOR ALONG WITH MULTIPLE  
LAUNCHES OF SAME PAYLOAD IN A  
GIVEN YEAR.

TOTAL FLIGHTS THIS LEG

47

PERCENT OF TOTAL

8.3%

Table 4-9. Payload Distribution for Shuttle Flights  
into 400 nmi Orbit ( $i = 28.5^\circ$ )

$h_a = h_p = 741$  km (400 nmi); Average Load Factor: 16%  
Average Volume Factor: 20%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	1	—	—	—	—
	1	—	8	—	—	—	—
	2	—	—	—	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

LIMITED TO ONE FLIGHT PER YEAR  
FOR NA2-9CR (17903 LB) AND  
NA2-10CR (3500 LB).

TOTAL FLIGHTS THIS LEG

9

PERCENT OF TOTAL

1.6%

Table 4-10. Payload Distribution for Shuttle Flights  
into 160 nmi Orbit ( $i = 55^\circ$ )

$h_a = h_p = 296 \text{ km (160 nmi)}$ ; Average Load Factor: 75%  
Average Volume Factor: 88%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	—	1	—	—	—
	1	—	1	2	—	—	—
	2	—	—	5	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

TUG REQUIRED ON ALL BUT INITIAL  
TWO FLIGHTS UTILIZED FOR NP 18 AND  
NP 19 WITH TUG LOAD FACTORS OF  
80%.

TOTAL FLIGHTS THIS LEG

9

PERCENT OF TOTAL

1.6%

Table 4-11. Payload Distribution for Shuttle Flights  
into 270 nmi Orbit ( $i = 55^\circ$ )

$h_a = h_p = 500$  km (270 nmi); Average Load Factor: 50%

Average Volume Factor: 56%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	11	1	—	—	—
	1	—	131	—	—	—	—
	2	—	—	6	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

MAJORITY OF TRAFFIC IN SPACE STATION  
RESUPPLY, DICTATED BY FIXED RECYCLE  
PERIOD.

TOTAL FLIGHTS THIS LEG

149

PERCENT OF TOTAL

26.5%

Table 4-12. Payload Distribution for Shuttle Flights  
into 160 nmi Orbit ( $i = 90^\circ$ )

$h_a = h_p = 296 \text{ km (160 nmi)}$ ; Average Load Factor: 41%  
Average Volume Factor: 66%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	—	—	—	—	—
	1	—	17	4	—	—	—
	2	—	—	27	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

31 FLIGHTS REQUIRED TO SUPPORT  
UPPER STAGE LEGS WHERE TUG LOAD  
FACTOR IS ONLY 2% OF FULL  
CAPABILITY.

TOTAL FLIGHTS THIS LEG

48

PERCENT OF TOTAL

8.5%

Table 4-13. Payload Distribution for Shuttle Flights  
into 270 nmi Orbit ( $i = 90^\circ$ )

$h_a = h_p = 500$  km (270 nmi); Average Load Factor: 4%  
Average Volume Factor: 30%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	2	—	—	—	—
	1	—	—	—	—	—	—
	2	—	—	—	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

LIMITED TO NE45LCR DEPLOYMENT;  
ONE FLIGHT EACH IN 1991 AND 1992.  
CAN BE COMBINED WITH NP16LCR IN  
1992.

TOTAL FLIGHTS THIS LEG 2

PERCENT OF TOTAL 0.4%



Table 4-14. Payload Distribution for Shuttle Flights  
into 500 nmi Orbit ( $i = 90^\circ$ )

$h_a = h_p = 926$  km (500 nmi); Average Load Factor: 77%  
Average Volume Factor: 35%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	2	—	—	—	—
	1	—	—	—	—	—	—
	2	—	—	—	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

LIMITED TO NP16LCR DEPLOYMENT;  
ONE FLIGHT IN 1982 AND ONE IN 1992  
OR NP13LCR IN 1982 IF TUG AVAILABLE.

TOTAL FLIGHTS THIS LEG 2

PERCENT OF TOTAL 0.4%

Table 4-15. Payload Distribution for Shuttle Flights  
into 160 nmi Orbit ( $i = 100^\circ$ )

$h_a = h_p = 296 \text{ km (160 nmi)}$ ; Average Load Factor: 45%  
Average Volume Factor: 84%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	—	—	—	—	—
	1	—	1	7	5	—	—
	2	—	—	16	2	—	—
	3	—	—	1	9	—	—
	4	—	—	—	—	—	—

ALL FLIGHTS SUPPORT UPPER LEG  
OPERATIONS.

TOTAL FLIGHTS THIS LEG 41

NEO-16LCR }  
NE-38LCR } 925 km (500 nmi)  
NE-42 LCR }

PERCENT OF TOTAL 7.3%

NEO-7LCR 1,296 km (700 nmi)

Table 4-16. Payload Distribution for Tug Launched from WTR  
into 500 nmi Orbit ( $i = 100^\circ$ )

$h_a = h_p = 926$  km (500 nmi); Average Load Factor: 5%

Average Volume Factor: 72%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	6	6	—	—	—
	1	1	1	2	—	—	—
	2	—	1	9	—	—	—
	3	—	—	—	—	—	—
	4	—	—	—	—	—	—

NEO-16 LCR 2,112 kg (4,658 lb)

NE-38 LCR 1,850 kg (4,088 lb)

NE-42 LCR 1,460 kg (3,223 lb)

Remaining upper leg to 1,297 km (700 nmi)  
has 15 flights for deployment of  
NEO-7 LCR 905 kg (1,998 lb).

TOTAL FLIGHTS THIS LEG 26

PERCENT OF TOTAL 36.1%

Table 4-17. Payload Distribution for Shuttle Flights  
into 500 nmi Orbit ( $i = 100^\circ$ )

$h_a = h_p = 926 \text{ km (500 nmi)}$ ; Average Load Factor: 0%  
Average Volume Factor: 0%

PAYLOADS		U P					
		0	1	2	3	4	5
DOWN	0	—	—	—	—	—	—
	1	—	—	—	—	—	—
	2	1	—	—	—	—	—
	3	1	—	—	—	—	—
	4	—	—	—	—	—	—

\* PRE - WTR TUG AVAILABILITY

TOTAL FLIGHTS THIS LEG 2

PERCENT OF TOTAL 0.4%

Table 4-18. Case 506 Unique Missions -- Planetary

PAYLOAD	LOGISTIC VEHICLE	MISSION ORBIT			CHARACTERISTIC VELOCITY		TOTAL NO. OF FLTS	AVERAGE	
		i, Deg.	h <sub>a</sub>	h <sub>p</sub>	mps	fps		LOAD FAC	VOL FAC
NU-37LCE	Tug	Planetary			11,130	(36,500)	2	18%	61%
NU-22LCE	Tug				11,550	(37,900)	2	55%	71%
NU-23LCE	Tug				11,550	(37,900)	2	37%	64%
NU-24LCE	Tug				11,780	(38,600)	1	10%	56%
NU-25LCE	Tug				11,770	(38,600)	4	19%	44%
NU-26LCE	Tug				11,770	(38,600)	4	11%	46%
NP-15LCE	Tug/A				12,200	(40,000)	7 T 1 A	13%	42%
NU-34LCE	Centaur				12,800	(42,000)	3	56%	83%
NU-27CE	Centaur				12,900	(42,300)	2	65%	83%
NU-33LCE	Cent/B2				13,410	(44,000)	4	58%	65%
NU-35LCE	Cent/B2				14,390	(47,200)	1	62%	68%
NU-36LCE	Cent/B2				14,390	(47,200)	4	60%	63%
NP-17LCE	Centaur				14,580	(47,800)	3	52%	40%
NU-31LCE	Centaur				14,720	(48,300)	4	63%	49%
NU-28LCE	Cent/B2				15,060	(49,400)	1	69%	72%
NU-32LCE	Cent/B2				15,060	(49,400)	3	72%	64%
NU-30LCE	Centaur				15,210	(49,900)	4	94%	48%
NU-29LCE	Cent/B2				15,620	(51,250)	2	67%	41%
NP-20LCE	Cent/B2				16,710	(54,500)	2	68%	52%

T = Tug  
A = Agena  
B2 = Burner II

Total Flights These Legs: Tug 22 ; Cent 16

Centaur/B2 17

Percent of Total: Tug 12% ; Centaur 45%

Centaur/B2 100%

current design weight 1,179 kg (2,600 lb) been employed, tandem Tugs would not have been required. However, since the tandem Tug was required, it was used efficiently, taking two payloads up and down on each flight. Also, Table 4-18 indicates the results of planetary operations. There are numerous cases in which the load factor is relatively low (less than 50%). However, little improvement can be expected because the volume factor is high. Again, if longshoring were employed, the results would change significantly. Also, a reevaluation of the payload definitions may show overly conservative definitions in terms of length. Further work is needed on planetary missions relative to multiple payload operations.

The results of Case 506 for low altitude Shuttle operations are shown in Table 4-19. The low values of load factor indicate a need for improving these operations. The operations in general were sortie operations and revisits to large scientific free-flying modules (i. e., Large Space Telescope). Dual revisits and dual sorties were allowed wherever reasonable, but the overall efficiency is low, both in load and volume factors. Combining all operations to one altitude might allow some increase in multiple operations. Another possible improvement is to combine these missions with space station revisits which also have a low load factor. This means reevaluating the mission objectives of those programs involved.

By comparing the 1972 excursion (Case 506) with the 1971 mission model (Case 403), it is possible to assess the impact of mission model perturbations. This is shown in Table 4-20 for mission legs which have a counterpart in each of the cases. Sorties and space station operations are excluded, since they did not exist in the 1971 model. It is shown that although the number of flights varied, as well as the individual payload weights, the loading efficiency remained approximately constant. The only significant point of departure is for WTR operations. Shuttle and Tug efficiencies both dropped, although the Tug was already relatively low. The Tug capability reflects the off-loading required for WTR operations and the load factors related to that capability.

Including sortie and space station operations in this overall comparison results in the values shown in Table 4-21. The overall efficiency

Table 4-19. Case 506 Summary of Low Earth Orbit Operations  
( $i = 28.5^\circ$ )

ALTITUDE		TOTAL FLIGHTS	LOAD FACTOR	VOLUME FACTOR
km	(nmi)			
463	(250)	13	39%	69%
556	(300)	47	22%	51%
741	(400)	9	16%	20%

Average Load Factor (69 Flights) 25%

Average Volume Factor (69 Flights) 50%

Table 4-20. Mission Characteristics Summary

Vehicle	Leg		Case 403		Case 506*	
	Inc. Deg.	Alt km (nmi)	Flights	Load Factor	Flights	Load Factor
Shuttle	28.5	296 (160)	331	80%	240	79%
	28.5	463 (250)	---	---	13	39%
	28.5	556 (300)	---	---	47	22%
	28.5	648 (350)	67	28%	---	---
	28.5	926 (500)	---	---	9	16%
Tug	0	35,786 (19,323)	191	67%	137	82%
Tandem Tug	0	35,786 (19,323)	10	96%	5	86%
Shuttle	90	296 (160)	33	87%	48	41%
	90	500 (270)	---	---	2	4%
	90	741 (400)	15	12%	---	---
	90	926 (500)	---	---	2	77%
WTR Tug	90	333 × 3,333 (180) × (1,800)	9	8.4%	8	2%
		556 × 5,556 (300) × (3,000) 1,850 × 37,040 (1,00 × 20,000)	15	4.5%	15	3%
Shuttle	100	296 (160)	18	96%	41	45%
	100	926 (500)	56	62%	---	---
WTR Tug	100	926 (500)	---	---	26	5%
	100	1,296 (700)	18	2%	---	---

\*Does not include missions which have no counterpart in 71 model.



Table 4-21. Overall Comparison by Vehicle

VEHICLES	1971 MODEL		1972 MODEL*	
SHUTTLE	520	75%	562	58%
TUG (ETR)	251	57%	182	71%
TANDEM TUGS	16	**64%(96%)	5	86%
WTR TUG	51	17%	72	7%
CENTAUR	13	82%	36	52%
AGENA	-0-	---	3	78%

\* INCLUDES SPACE STATION  
AND SORTIE MISSIONS

\*\* APPLICABLE TO 10 SYNC  
EQ MISSIONS

of the Shuttle dropped to 50% while the Tug for ETR operations increased to 71%. In general, the following conclusions can be drawn.

a. The loading technique employed results in comparable multiple payload applications and is not overly sensitive to the mission model definition. This implies that the distributed cost of launching a given payload program should remain fairly stable from one mission model to the next provided that the individual program is not deleted. Consequently, analysis of operational concepts should not be sensitive to the mission model and comparative type results should be valid and relatively stable on an individual program by program basis.

b. The overall efficiency of operations for Case 506 is considerably less than for the 1971 mission model baseline, Case 403. Although some ground rules are different, as given in Ref. 8, they do not invalidate this conclusion.

## 5. VELOCITY REQUIREMENTS FOR MULTIPLE PAYLOAD OPERATIONS

As an adjunct to analyzing the missions described in previous sections, it has been necessary to develop a set of parametric supporting data. This information is in the form of impulsive velocity requirements for upper stage vehicles. Once the velocity requirements are developed, they can then be tested against various upper stage configurations for efficiency of operations.

Three areas of concern are addressed:

- a. Characteristic velocity for synchronous equatorial missions.
- b. Phasing velocity requirements to service several payloads in a given orbit.
- c. Velocity requirements to service more than one orbit and the associated launch window.

### A. SYNCHRONOUS EQUATORIAL MISSIONS

The characteristic velocity for synchronous equatorial missions has been addressed by numerous agencies, including NASA Marshall Space Flight Center and Johnson Space Center. However, there are subtle differences between their flight data that result in a 61 mps (200 fps) to 122 mps (400 fps) velocity difference which has a significant effect on the Tug servicing capability for multiple payload operations. The selected characteristic velocity is sensitive to the number of burns at injection into the transfer ellipse, the thrust-to-weight ratio, and the out-of-plane steering technique. Consequently, it has been necessary to reassess the values to be employed in future operations analyses.

The MSFC baseline Tug definition (cryogenic) employed a single perigee burn but neglected the effective rise in perigee which occurs with non-impulsive thrusting. The initial thrust-to-weight ratio was 0.15, resulting in gravity losses of 94.5 mps (310 fps). Out-of-plane steering was included but the allocation was not broken out. A summary of the velocity requirements is given in Table 5-1.

Table 5-1. Characteristic Velocity  
Low Earth Orbit to Synchronous Equatorial

Tug Design/Agency	Delta V Requirements, mps (fps)				Comments
	Perigee Burn, mps	Apogee Burn, mps	Longit Adjust mps (fps)	Total, mps	
A. MSFC Baseline Cryogenic ( $I_{sp}$ = 470, T/W = 0.15)					
1. MSFC Estimate	2,542 (8,340 fps)	1,788 (5,868 fps)	-0-	4,330 (14,208 fps)	Includes gravity losses and out-of-plane steering; neglects rise in perigee.
2. Aerospace Single-burn inject	2,545 (8,350 fps)	1,771 (5,809 fps)	-0-	4,316 (14,159 fps)	
Two-burn inject	2,476 (8,122 fps)	1,781 (5,843 fps)	9.1 (30)	4,266 (13,995 fps)	
B. JSC Storable Tug (025) ( $I_{sp}$ = 339 sec, T/W = 0.1)					
1. JSC Estimate	2,202 (8,225 fps)	1,802 (5,913 fps)	-0-	4,309 (14,138 fps)	Two-burn injection.
2. Aerospace Single-burn inject	2,627 (8,619 fps)	1,759 (5,770 fps)	-0-	4,386 (14,389 fps)	Includes out-of-plane steering.
Two-burn inject	2,513 (8,246 fps)	1,776 (5,826 fps)	13.7 (45)	4,302 (14,117 fps)	Includes out-of-plane steering.

The value selected for future analysis (applicable both to cryogenic and storable tugs) is Delta V = 4,309 mps (14,138 fps) one way.

The NASA JSC storable Tug identified as Model 025 is assumed as another candidate for the Shuttle upper stage. A two-burn injection was employed by JSC to compensate for the reduced thrust-to-weight ratio ( $T/W = .10$ ). The velocity requirements for the JSC Tug likewise are summarized in Table 5-1. The total one-way requirement was estimated as 4,309 mps (14,138 fps) or 21 mps (70 fps) less than the MSFC baseline value. However, if a two-burn injection were employed with the cryogenic Tug, this velocity difference reverses.

Consequently, a set of values based upon Aerospace velocity estimates have been selected for future analysis. The same value will be employed for both cryogenic and storable upper stages. Yaw steering has also been assumed and an allowance for longitude placement has been included. The Aerospace values for the single and two-burn injection condition were averaged to arrive at a characteristic velocity of 4,309 mps (14,138 fps) one way from 296 km (160 nmi) orbit to synchronous equatorial orbit. A two percent velocity margin will be incorporated also when evaluating upper stage performance capabilities.

#### B. PHASING VELOCITY REQUIREMENTS -- SINGLE ORBIT

The capability to service numerous payloads within a given orbit was investigated by first defining the impulsive velocity requirements. This was performed parametrically assuming the satellites to be serviced were spaced equidistant within that orbit. It was also assumed that the satellites were coplanar, implying either that the satellites were launched simultaneously or launched in-plane. Out-of-plane maneuvers are discussed in Subsection C.

##### 1. Synchronous Equatorial Orbit Phasing

Impulsive transfers from one position to another were developed as a function of time. Both internal and external transfer ellipses were employed to bound the incremental velocity requirements. The equations and related coefficients are shown in Table 5-2 for reference.

Figure 5-1 provides the phasing velocity requirements for synchronous equatorial orbit. Although continuous lines are shown so that trends can be observed, it should be noted that the carpet plot is only valid at the discrete points of intersecting lines.

Table 5-2. Orbital Phasing Calculations

Definitions	Functions
$N$ = number of satellites to be serviced, 2, 3, 4, 5, 10, 20, 30	$a_1 = r_a = r_o + L$
$n$ = number of orbital revolutions to perform service to $N$ satellites $n \geq N - 1$	$P_1 = P_o \left( \frac{r_o + h}{r_o} \right)^{3/2}$
$T_{total}$ = total time to service $N$ satellites	$P_2^* = P_1 \left[ 1 - \frac{1}{nN} \right]$ (internal transfer)
$P_1$ = nominal circular orbit	$a_2 = a_1 \left( \frac{P_2}{P_1} \right)^{2/3}$
$P_2$ = phasing orbit period	$r_p = 2a_2 - r_a$
$\Delta V$ = incremental velocity between the phasing	$V_{cp} = V_{co} \sqrt{\frac{r_o}{r_p}}$
$V_{ca}, V_{cp}$ = circular velocity at apogee or perigee of phasing ellipse	$\frac{\Delta V_a}{V_{cp}} = \left  \sqrt{\frac{1}{\frac{r_a}{r_p}}} - \sqrt{\frac{2}{\frac{r_a}{r_p} \left( 1 + \frac{r_a}{r_p} \right)}} \right $
$h$ = nominal circular orbit altitude	$\Delta V_{total} = 2(N - 1) \Delta V_a$
$r_a$ = apogee altitude of phasing ellipse	$T_{total} = n(N - 1) P_2$
$r_p$ = perigee altitude of phasing ellipse	
$r_o$ = reference earth radius 3443.9336 nmi	
$V_{co}$ = circular orbit reference velocity (at $L = 0$ )  = 25,936.27 fps	$^* P_2 = P_1 \left[ 1 + \frac{1}{nN} \right]$ (external transfer)
$P_o$ = reference orbital period (at $L = 0$ )  = 84,48933 min = 0.058834 days	

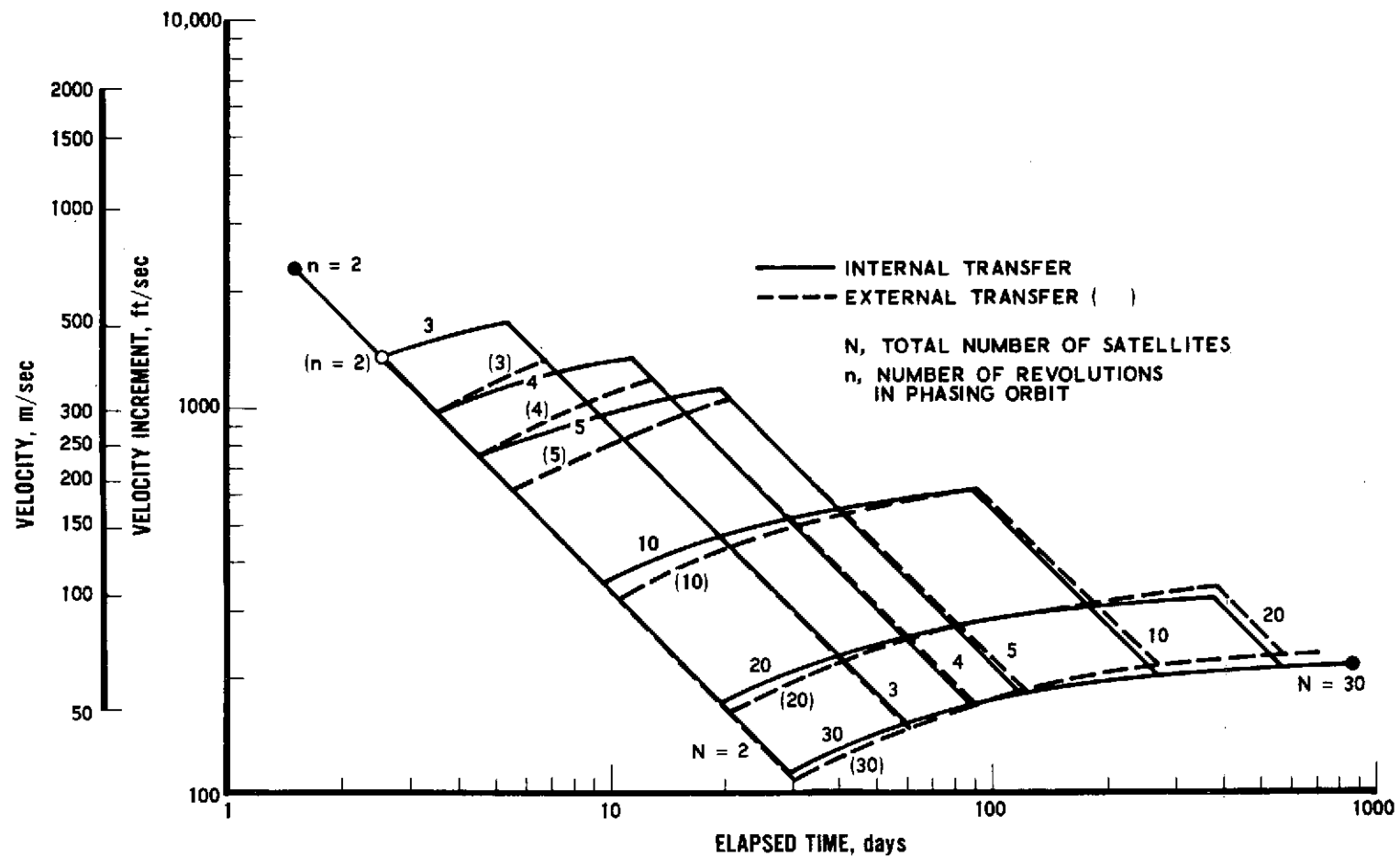


Figure 5-1. Phasing Velocity Requirements for Distributing Satellites in a Synchronous Equatorial Orbit

For example, if two satellites are serviced (requiring one transfer maneuver) the transfer could be performed in one-and-one-half days, using two revolutions of the phasing orbit and requiring a phasing velocity increment of 700 mps (2,300 fps). If that same maneuver were performed over approximately a 10-day period, 10 revolutions would be required but the velocity increment would be reduced to 107 mps (350 fps); almost an order of magnitude reduction. If an external transfer were employed, an additional saving of 11 mps (35 fps) could be realized.

If three satellites were to be serviced, spaced at 120 degrees in the orbit, the velocity requirements would be substantially increased if the same period of time were involved. If the on-orbit period of a Tug is restricted to six days, the minimum phasing velocity increments would vary from 170 mps (560 fps) for two satellites to 500 mps (1,650 fps) for three satellites. Servicing more than three satellites requires non-optimum phasing maneuvers resulting in velocity requirements in excess of 762 mps (2,500 fps).

These results can be used in subsequent trade-offs of logistic vehicle requirements for payload performance capability versus the number of satellite stations to be serviced. An additional increment for rendezvous and docking maneuvers of 14 mps to 15 mps (45 to 50 fps) for each action should also be allowed.

## 2. Low Altitude Phasing

Servicing multiple satellites at low altitudes also may have economic benefits. Figure 5-2 shows the incremental phasing velocity to service multiple satellites in a 185 km (100 nmi) orbit. The satellites would be required to be coplanar. This will occur in some cases where multiple payloads are deployed simultaneously with one Shuttle flight. It may also occur where a second payload is launched in-plane with an existing satellite. The intent here is to provide the data which may be employed in subsequent trade-offs of multiple payload operations rather than to establish if a requirement exists. The velocity requirements to service two satellites varies from 91 to 1,830 mps (300 to 6,000 fps), depending upon the allotted



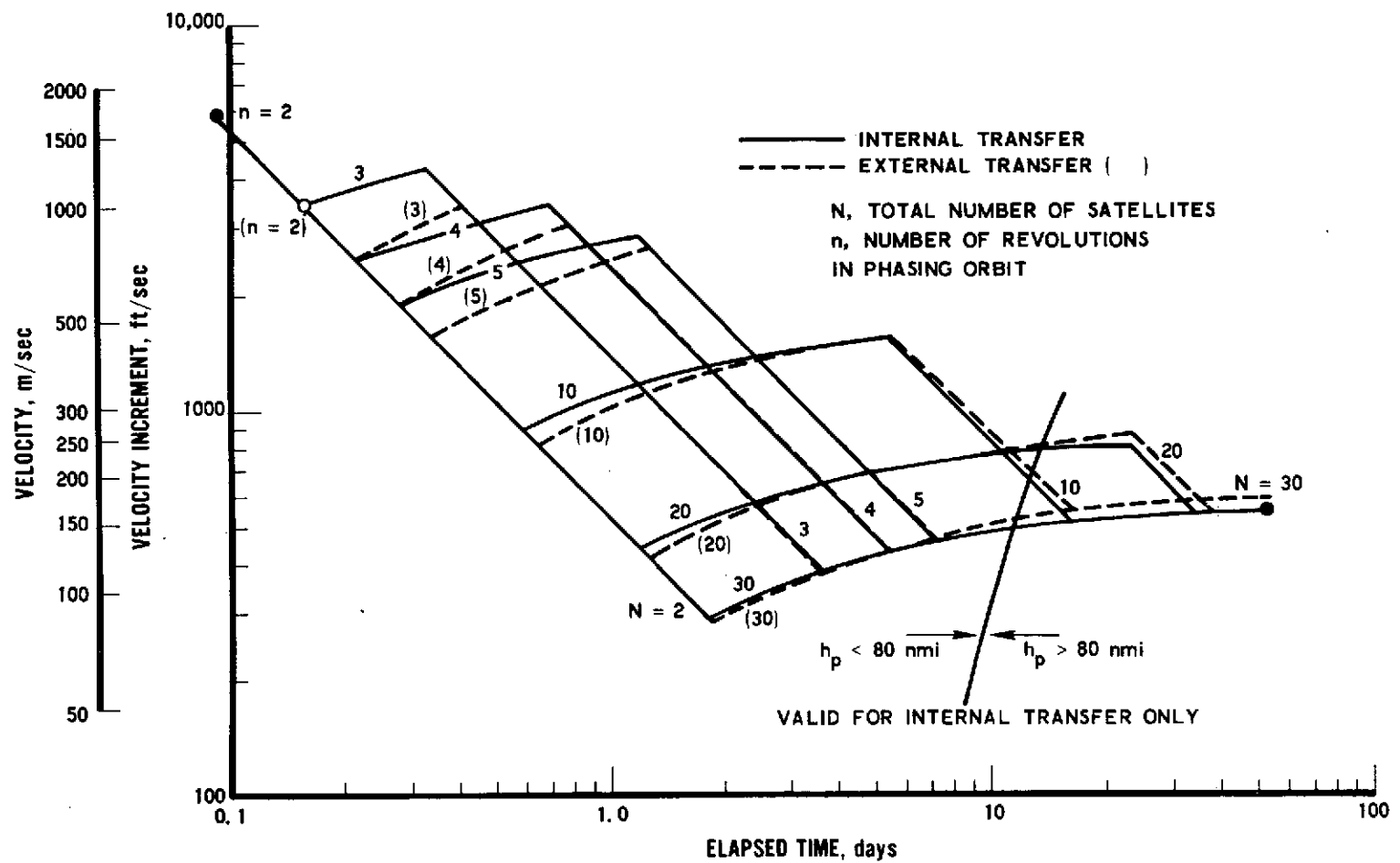


Figure 5-2. Phasing Velocity Requirements for Distributing Satellites in a 100 nmi Circular Orbit

time. Since two days does not appear to impose any constraint on the Shuttle, it can be assumed that a value of 91 mps (300 fps) is acceptable. A lower bound of 61 mps (200 fps) could be employed, requiring three days, if Shuttle performance is marginal. The additional velocity required to service up to five satellites is relatively modest and still lies within a seven-day operational ground rule. Because of the seven-day orbit duration requirement, low altitude internal transfers are not practical, but are shown on Figure 5-2 to indicate the sensitivity of data. In particular, the boundary line shows where the perigee altitude falls below 148 km (80 nmi) if internal transfers are employed.

Figure 5-3 shows a similar carpet plot for a 556 km (300 nmi) circular orbit for both internal and external coplanar transfers. External transfers can provide a substantial savings in velocity but the elapsed time is increased. The minimum altitude boundary for internal transfers is also shown for reference. Figure 5-4 provides the same data for a 1,111 km (600 nmi) orbit.

For low altitude orbits, the velocity requirements to phase from one position to another can be assumed to lie between 91 and 122 mps (300 and 400 fps) for most applications. This supports visiting up to four satellites, which is a reasonable upper bound based upon the results shown in Sections 3 and 4. If the satellites are not equidistant within the orbit (i. e., are clustered in one region), the incremental velocity requirements would be reduced. Consequently, these values appear to represent a reasonable upper bound. Also, since out-of-plane maneuvers require an excessive amount of energy, there is a distinct incentive to launch payloads in-plane so that multiple servicing can be employed. This may require adjustment of the baseline mission model to cluster payloads with similar orbital requirements around fixed launch dates.

Out-of-plane maneuvers can be employed in certain specific cases. The following Subsection C goes into this point in detail for various combinations of elliptical and circular orbits required by the 1972 excursion of the baseline mission model. However, there is also some applicability at synchronous altitudes. Synchronous explorer satellites (NA2-2) are small

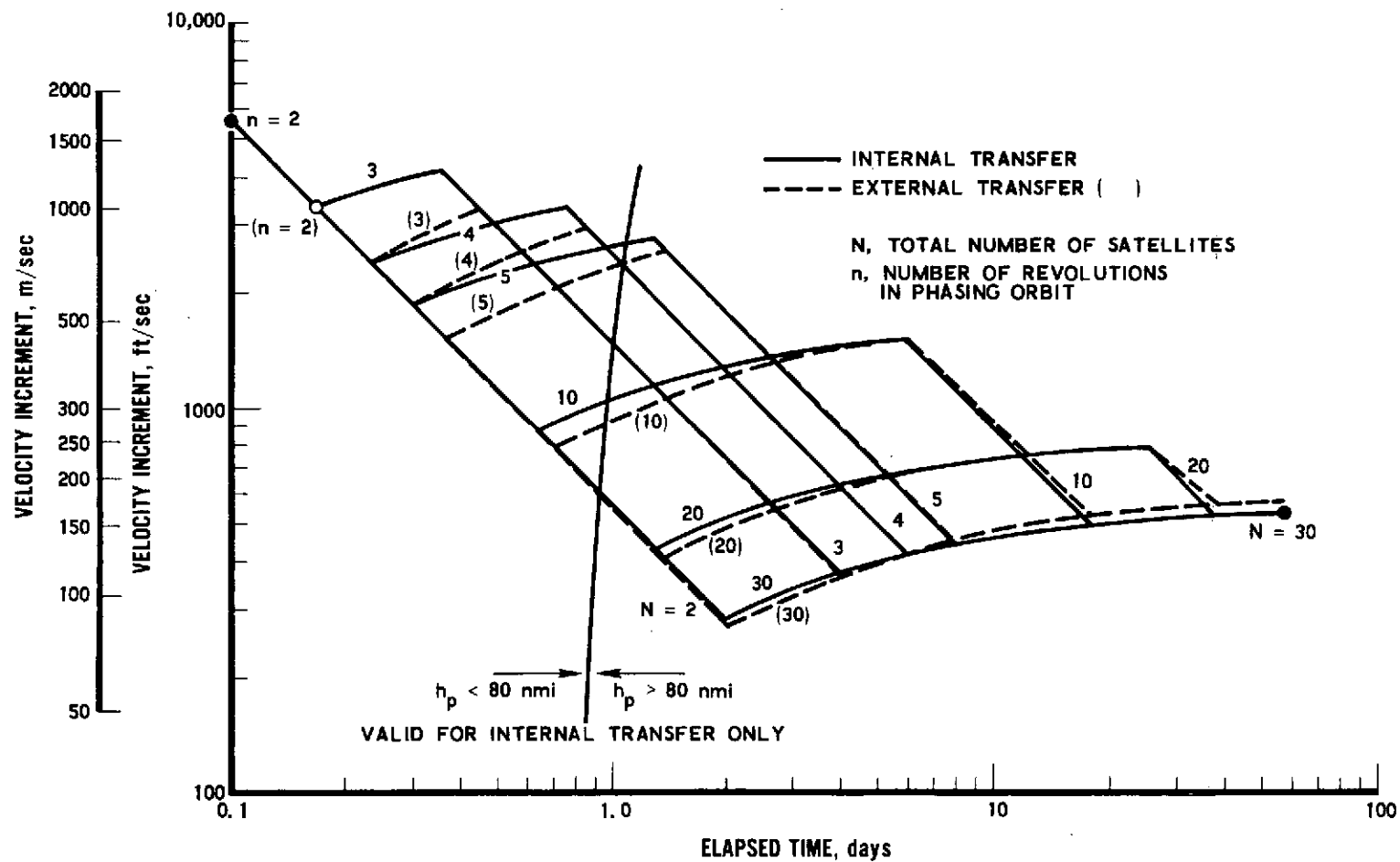


Figure 5-3. Phasing Velocity Requirements for Distributing Satellites in a 300 nmi Circular Orbit

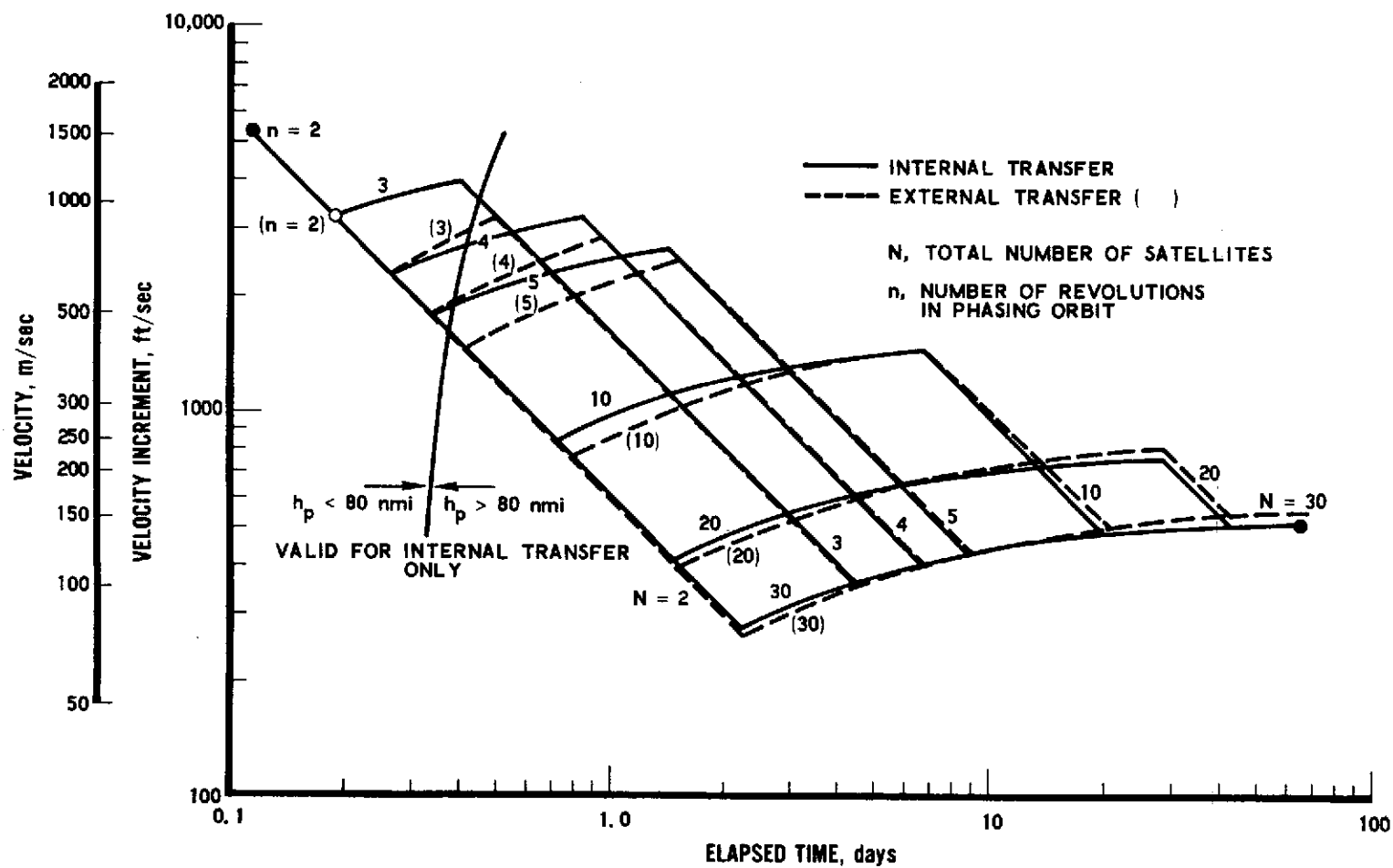


Figure 5-4. Phasing Velocity Requirements for Distributing Satellites in a 600 nmi Circular Orbit

payloads, 181 kg (400 lb), placed at synchronous altitude but with an inclination of 28.5 degrees. The MSFC baseline cryogenic Tug has sufficient capability to deploy 2,722 kg (6,000 lb) or service 1,089 kg (2,400 lb) satellites in an equatorial orbit and subsequently deploy or retrieve the explorer payload at 28.5 degrees prior to the return transfer to low earth orbit. The incremental velocity requirement is approximately 1,158 mps (3,800 fps), or a 12% increase over the nominal requirement. If the "low cost design" approach of LMSC is employed, the weight is increased to 363 kg (800 lb), forcing dedicated flights. Four Tug flights and one expendable launch vehicle (Titan IIIB/Agena) are specified in the current Case 506 traffic model. The Tug flights require dedicated Shuttle flights amounting to approximately 50 million dollars in operations costs. Allowing plane change maneuvers (assuming the current design weight) would reduce these costs by an order of magnitude, or approximately 45 million dollars savings to the particular payload program, NA2-2.

C. Phasing Velocity Requirements -- Multiple Orbits

There are several missions in Case 403 and Case 506 which have unique orbits with little traffic. These missions therefore bear the full transportation cost for deployment and retrieval. However, in examining the performance load factors discussed in Sections 3 and 4 it was noticed that in many cases there is excess performance capability in the Tug for these particular missions. Therefore, various combinations or mission orbits were analyzed to determine the velocity requirements for deployment and servicing of multiple payload programs. It is also necessary to consider when subsequent servicing opportunities (launch windows) will occur, recognizing that the orbits regress relative to one another. In this way, it may be possible to increase multiple payload operations and thereby reduce the operations costs allocated to each individual payload program.

Table 5-3 lists the orbits of interest which offer potential savings if multiple servicing could be employed. Various combinations of orbits were examined originating from an initial orbit of 278 km (150 nmi) for due east orbits or from 185 km (100 nmi) for polar orbits. The first set of

Table 5-3. Candidate Mission Orbits for Multiple Operations

Orbit Inclination	Initial Orbit, km (nmi)	Altitude		Notes
		Final Orbit, km (nmi)		
		Apogee	Perigee	
28.5°	278 (150)	463 (250) 551 (297) 556 (300) 611 (330) 741 (400)	463 (250) 551 (297) 556 (300) 611 (330) 741 (400)	Examine Transfers for various combinations
0° to 28.5°	278 (150)	35,786 (19,323) 35,786 (19,323)	35,780 (19,323) 35,780 (19,323)	Change inclinations at synchronous altitude
55°	185 (100)	500 (270) 12,800 (6,900)	500 (270) 12,800 (6,900)	
90°	185 (100)	333 (180) 556 (300) 1,889 (1,020)	3,333 (1,800) 5,556 (3,000) 37,040 (20,000)	Examine transfer for various combinations
98° to 99.2°	185 (100)	926 (500) 926 (500)	926 (500) 926 (500)	Plane change maneuver
99.2 100.9 103	185 (100)	926 (500) 1,296 (700) 1,678 (906)	926 (500) 1,296 (700) 1,678 (906)	Plane change and orbit altitude change

data relates to performing operations with the Tug in low earth orbit prior to transferring to synchronous equatorial orbit. Figure 5-5 shows the impact on the baseline Tug's synchronous servicing capability if another payload is first deployed in a low earth orbit up to 741 km (400 nmi). If the Tug is scheduled to service 907 kg (2,000 lb) in synchronous orbit it could also deploy 3,175 kg (7,000 lb) at 741 km (400 nmi) on the same mission. If servicing in low earth orbit is required, the results would be as shown in Figure 5-6. If the Tug is scheduled to service 907 kg (2,000 lb) at synchronous equatorial, it could also service 453 kg (1,000 lb) at 741 km (400 nmi). In this particular case, the equipment picked up at 741 km (400 nmi) is transported to synchronous equatorial orbit before being returned to the Shuttle. If it were possible to service the payload at 741 km (400 nmi) and tether the failed modules for pickup on the return trip from synchronous equatorial, the performance capability would hardly be impacted.

The impulsive velocity requirements to perform servicing at two non-coplanar orbits at 28.5 degrees inclination are shown in Figures 5-7 through 5-12. It is assumed that the Shuttle can be launched in-plane with the lower altitude orbit; consequently, the first leg of the Tug operation would not require a plane change. A plane change would be required on the next leg and also on the return leg to place the Tug in the proper orbit for retrieval. In all cases the operations are compatible with a seven-day operational requirement. Figure 5-13 shows the results of servicing three orbits at 28.5 degrees inclination. The nodal regression is such that a return servicing opportunity only occurs every two to three years. The associated launch window is approximately four months in length. This is based upon a Tug servicing requirement of 1,000 kg (2,200 lb). Reducing the servicing weight requirements would not provide any substantial improvement. Consequently, this combination of orbits is not suitable for multiple service operations.

The requirements for inclinations of 55 degrees are shown in Figure 5-14. The servicing launch window occurs every two months and lasts for approximately three weeks. Except for high priority payloads, this should be acceptable for servicing operations.

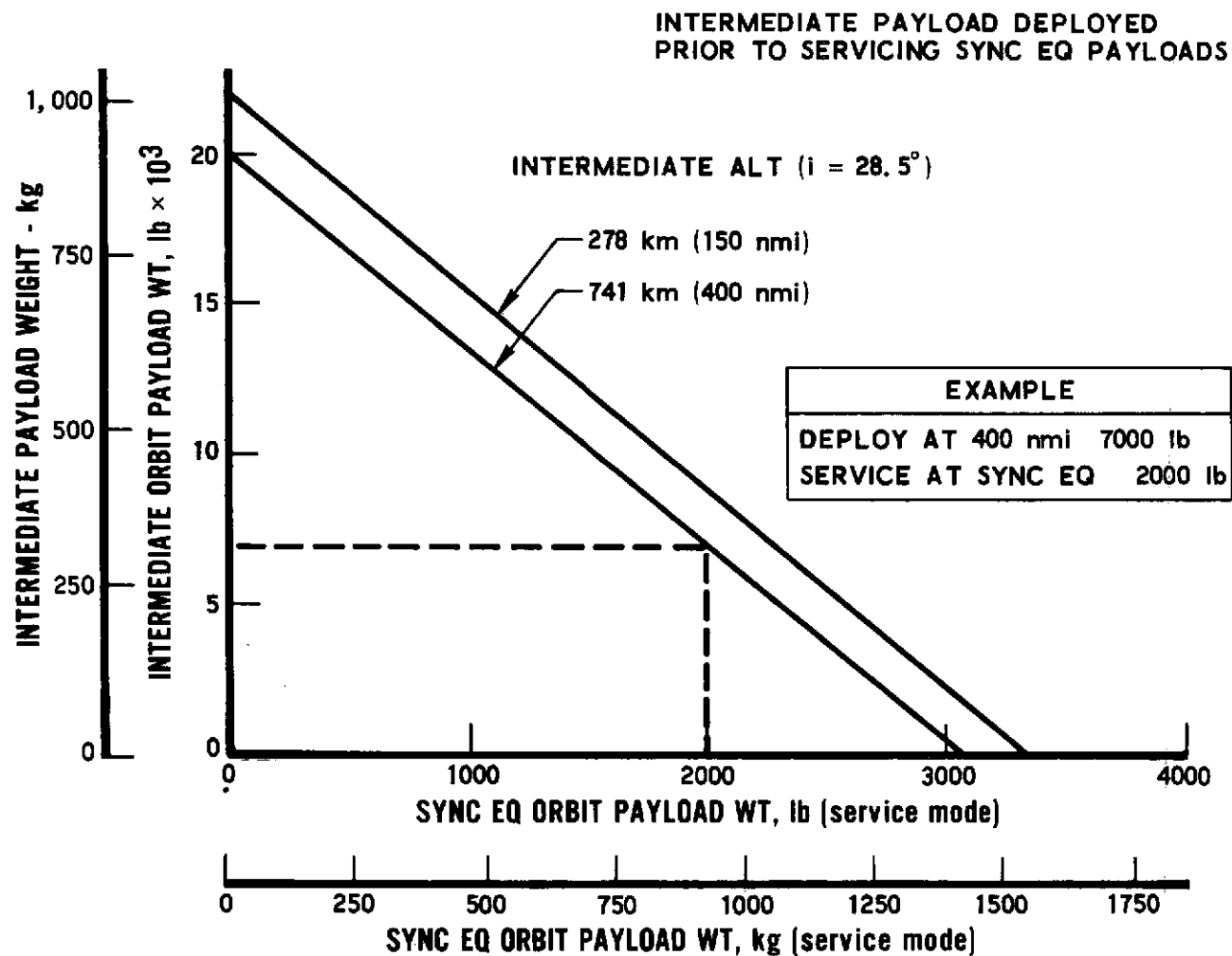


Figure 5-5. Tug Capability: Intermediate Payload Deployed Prior to Servicing Synchronous Equatorial Payload



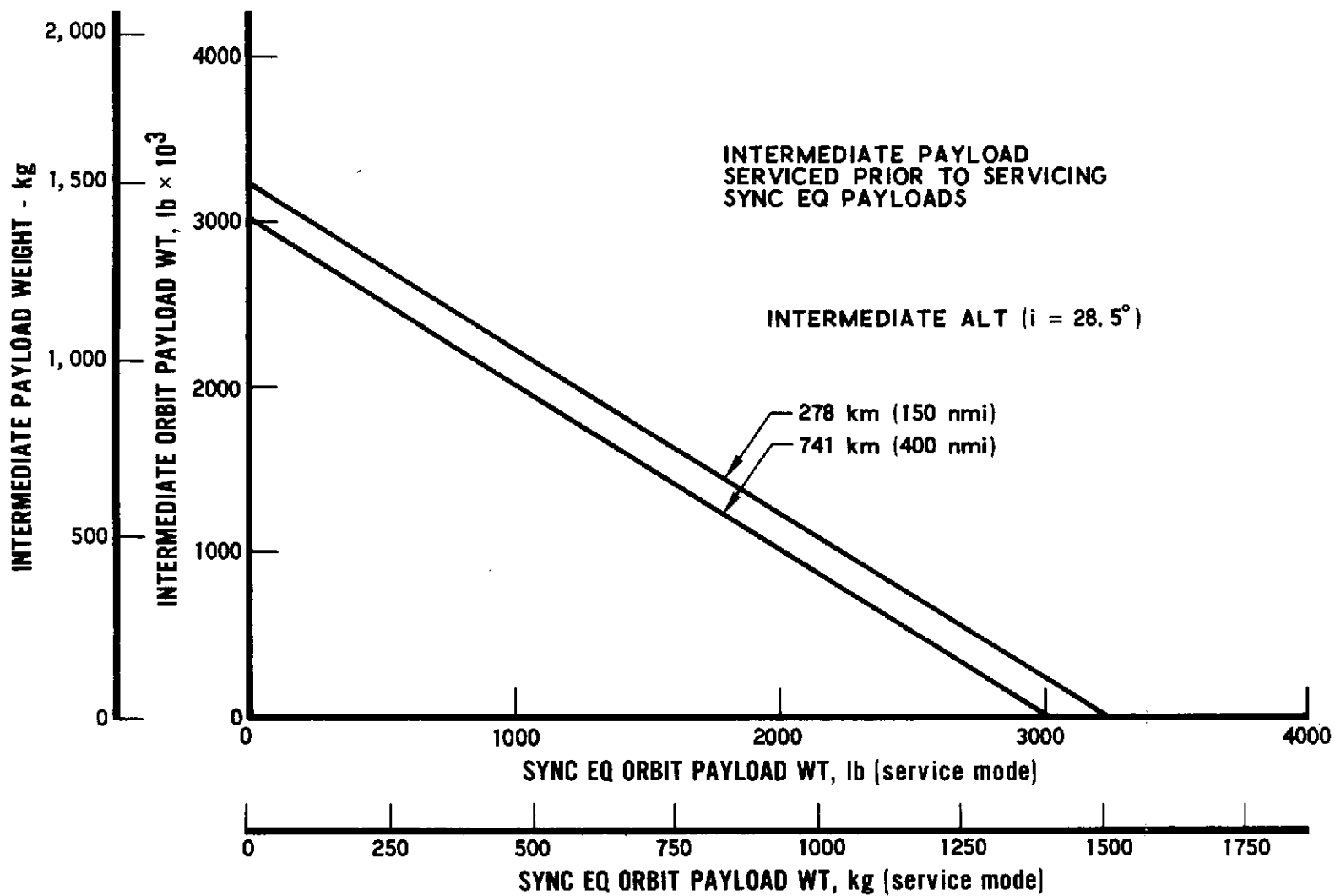


Figure 5-6. Tug Capability: Intermediate Payload Serviced Prior to Servicing Synchronous Equatorial Payload

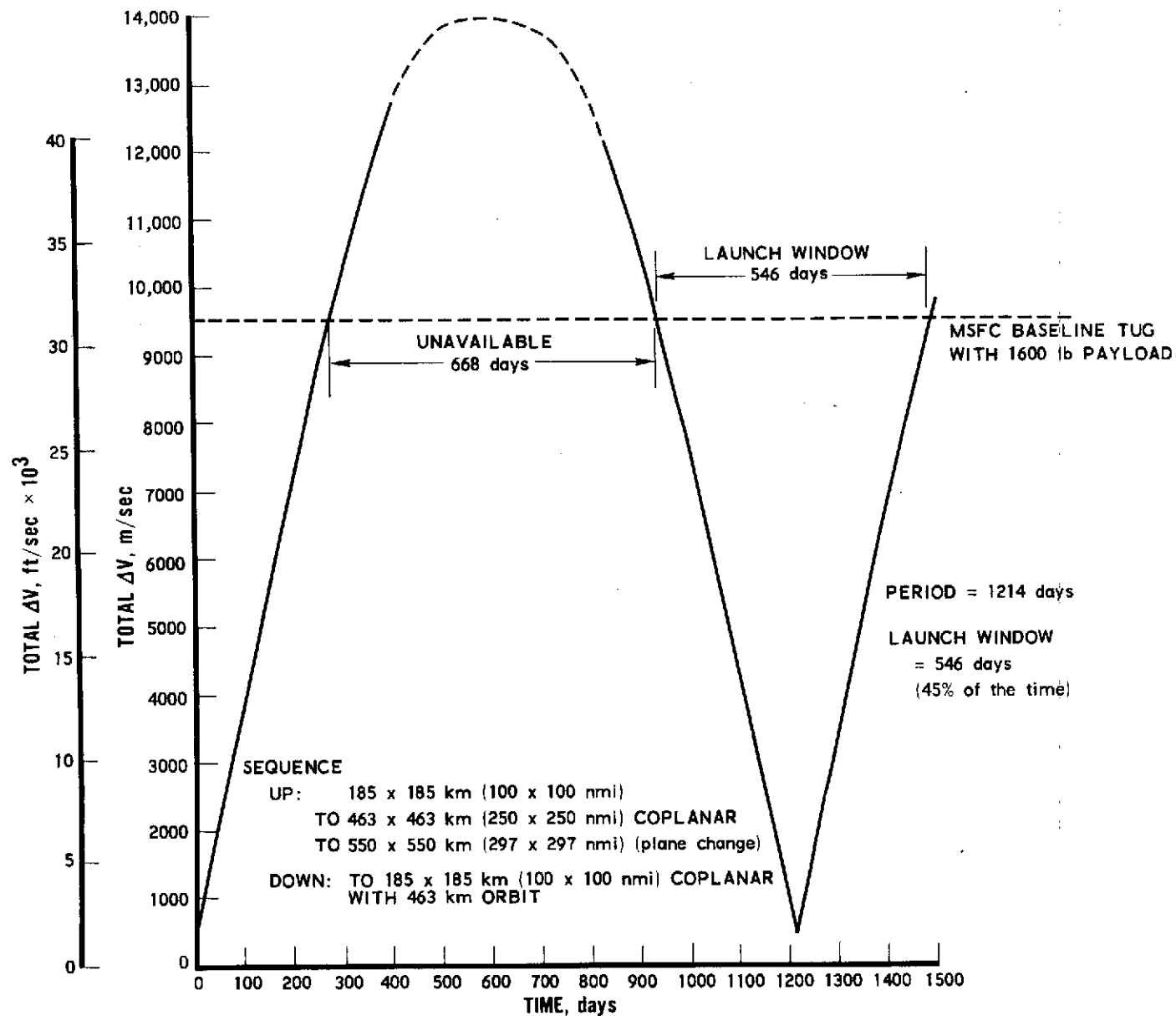


Figure 5-7. Velocity Requirements to Service Two Orbits at 28.5 deg Inclination

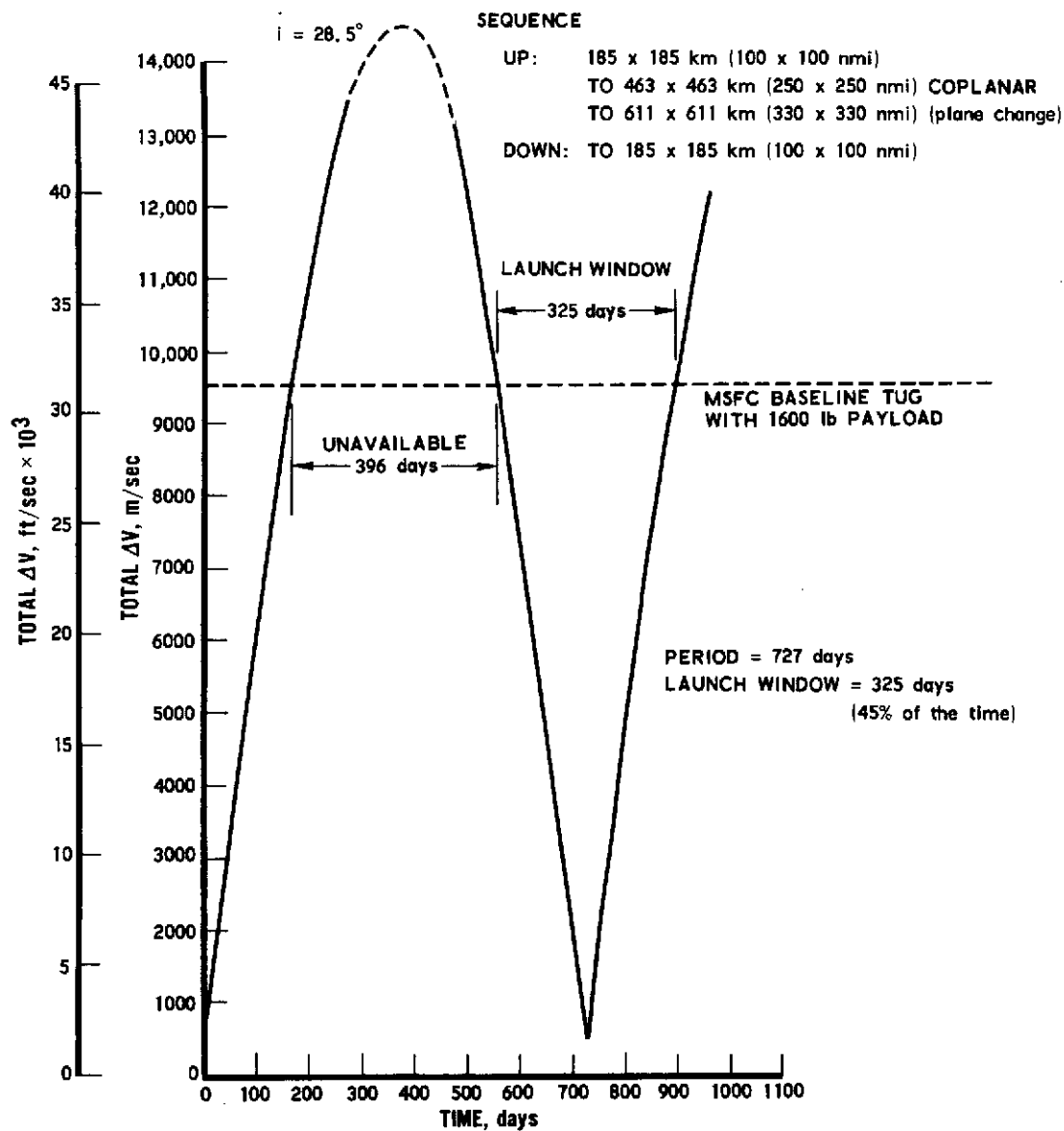


Figure 5-8. Velocity Requirements to Service Two Orbits at 28.5 deg Inclination

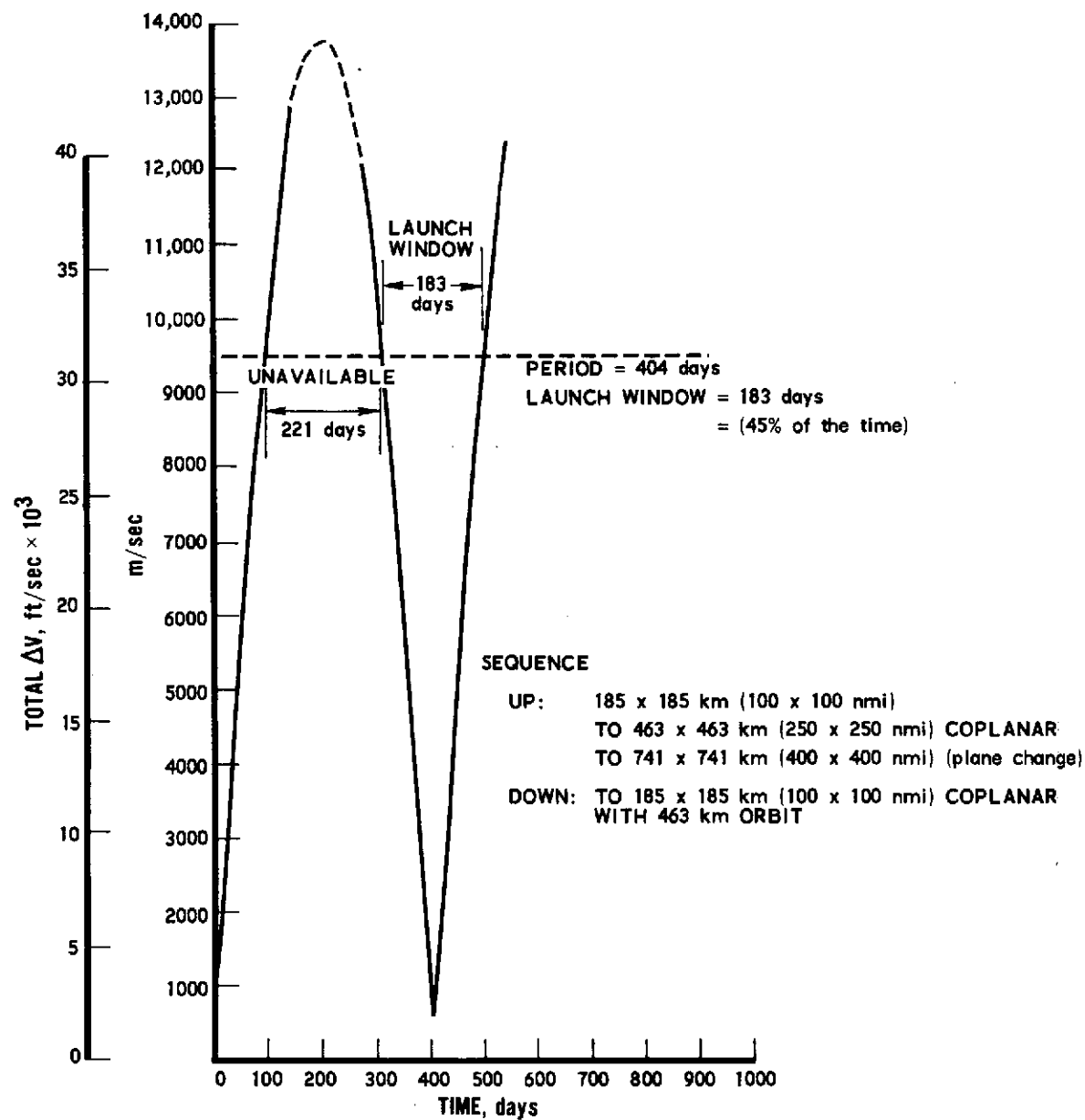


Figure 5-9. Velocity Requirements to Service Two Orbits at 28.5 deg Inclination

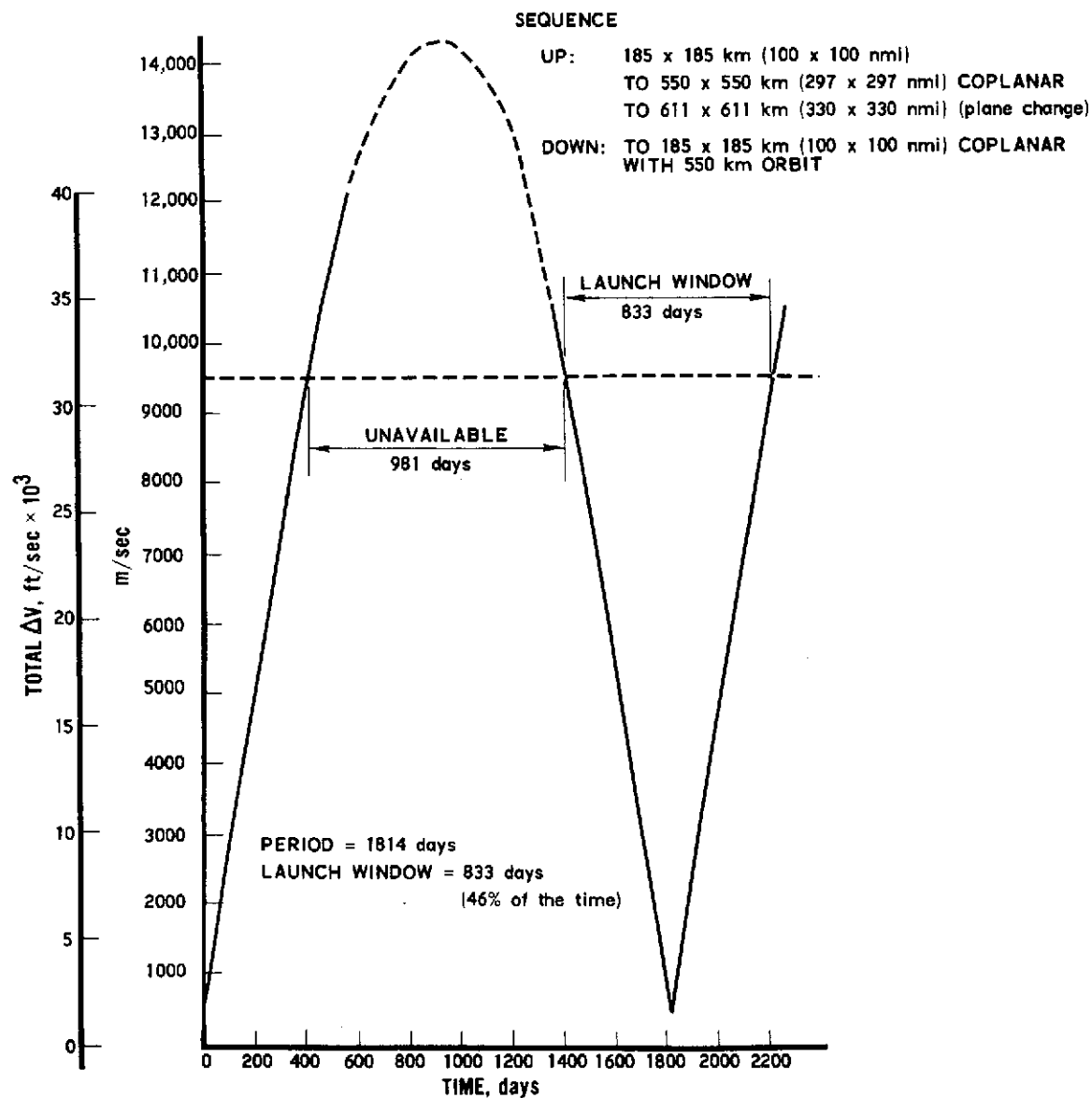


Figure 5-10. Velocity Requirements to Service Two Orbits at 28.5 deg Inclination

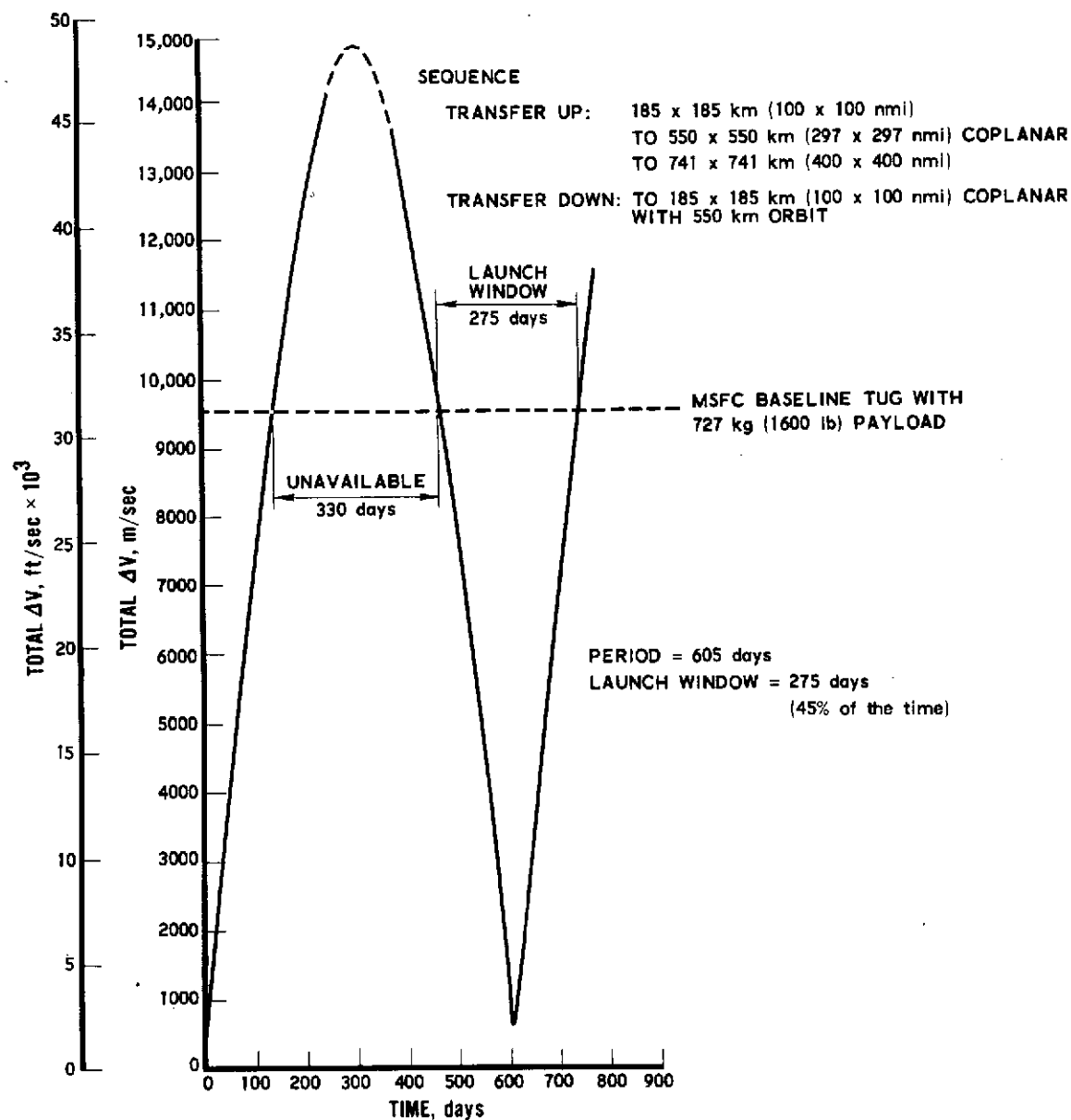


Figure 5-11. Velocity Requirements to Service Two Orbits at 28.5 deg Inclination

# SEQUENCE

UP: 185 x 185 km (100 x 100 nmi)  
 TO 611 x 611 km (330 x 330 nmi) COPLANAR  
 TO 741 x 741 km (400 x 400 nmi) (Plane Change)  
 DOWN: TO 185 x 185 km (100 x 100 nmi) INITIAL ORBIT

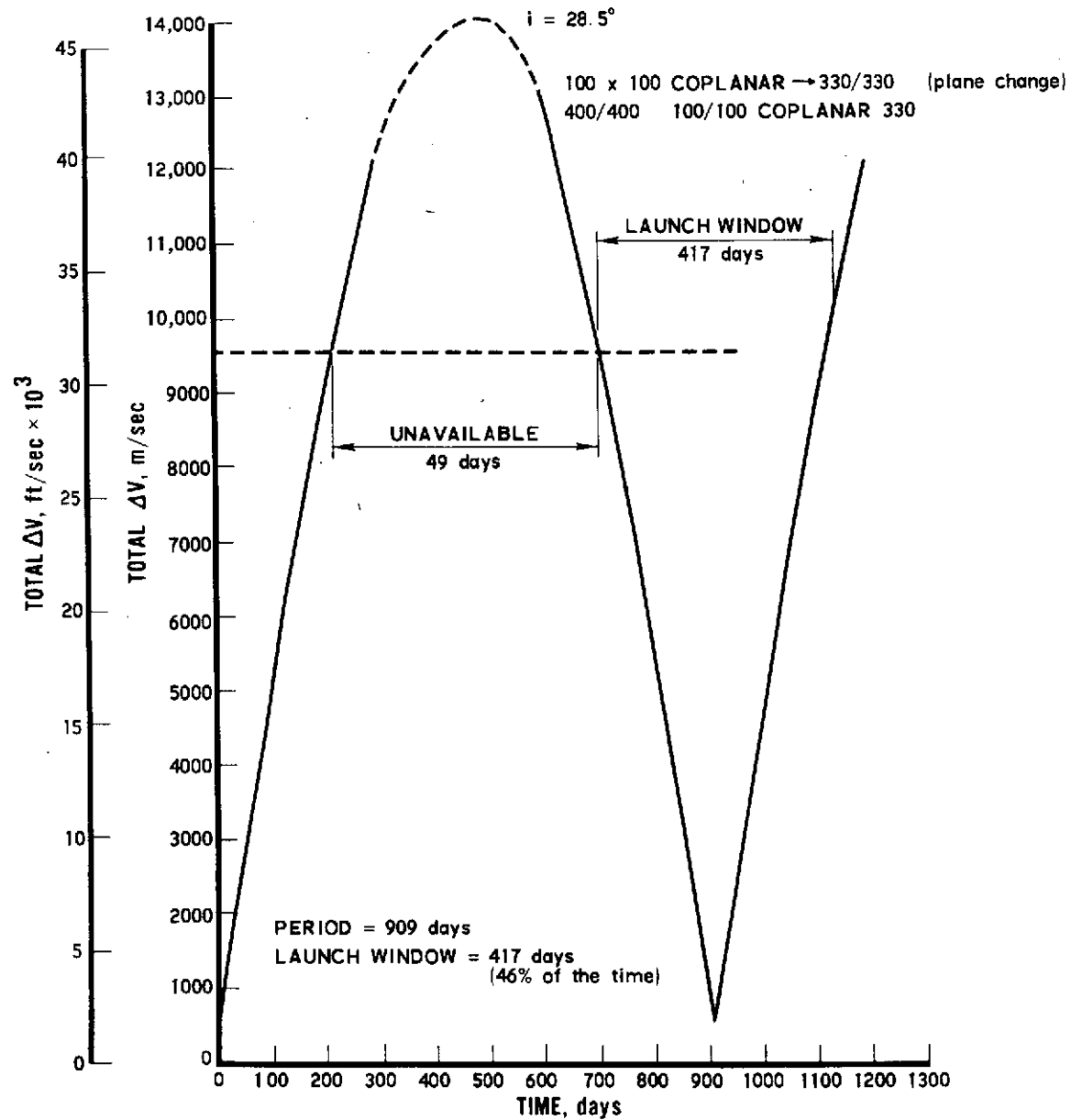


Figure 5-12. Velocity Requirements to Service Two Orbits at 28.5 deg Inclination

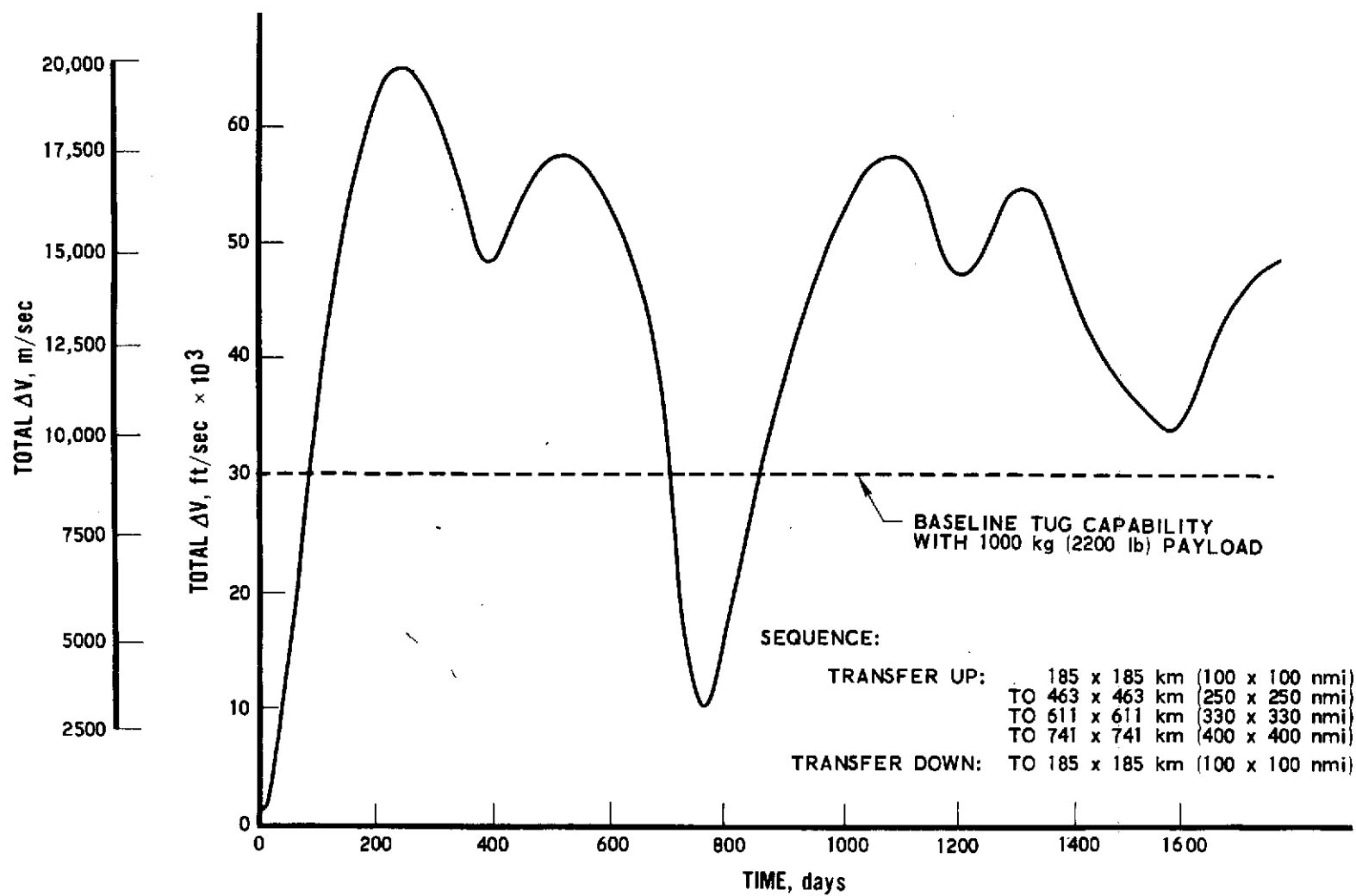


Figure 5-13. Velocity Requirements to Service Three Orbits at 28.5 deg Inclination



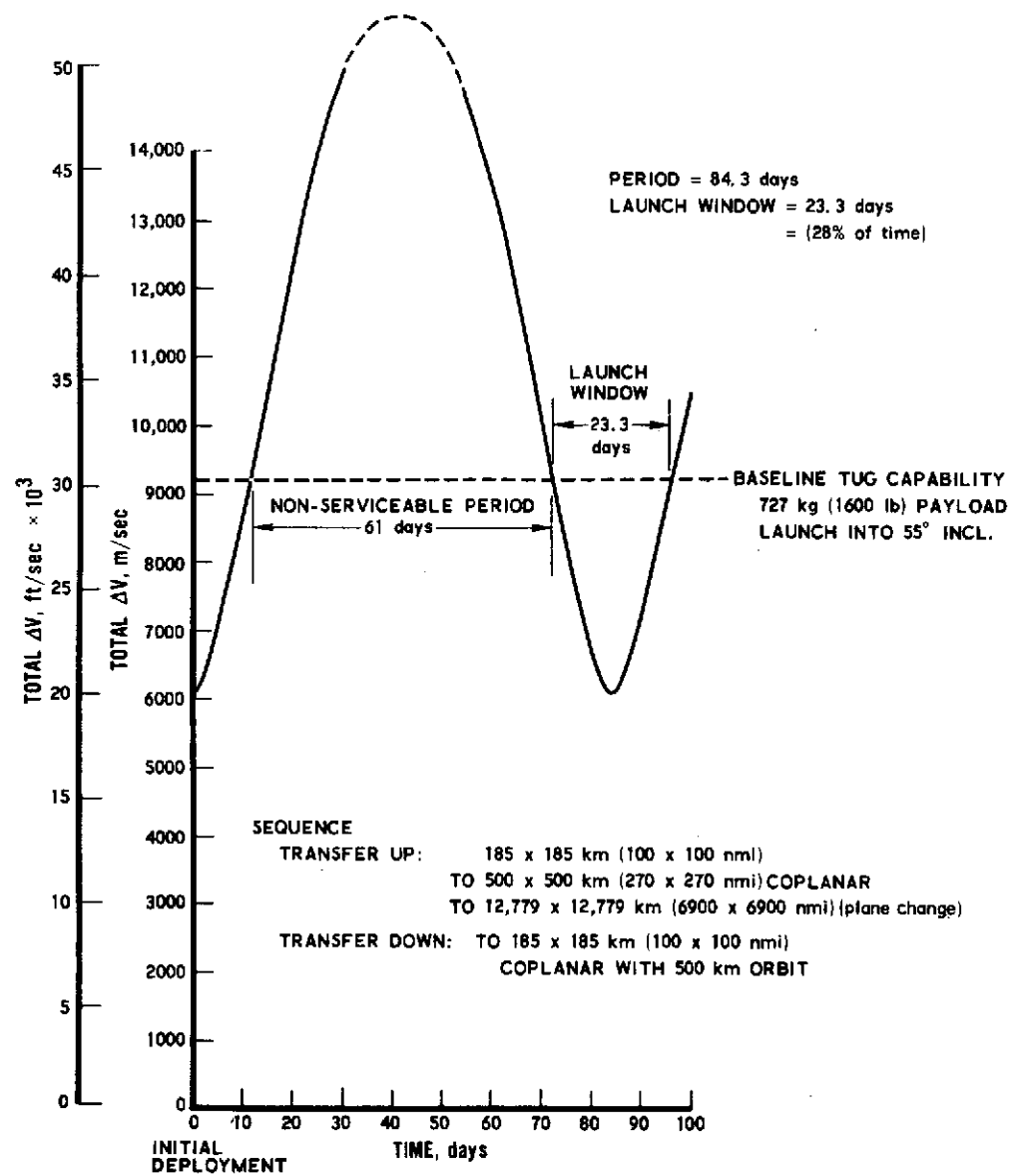


Figure 5-14. Velocity Requirements to Service Two Orbits at 55 deg Inclination

At 90 degrees inclination, nodal regression is no longer applicable but rotation of the line of apsides is. The relative importance depends on the orbit altitude and eccentricity. Transfers between elliptical orbits are shown in Figure 5-15. For these cases the Tug (off-loaded to be Shuttle compatible) has more than adequate performance capability. Therefore, a third orbit was added providing the results shown in Figure 5-16. There are numerous launch window opportunities for various servicing weights. As a point of comparison, Case 506 of the 1972 mission model excursion identifies 39 flights in the time period of interest (31 Shuttle plus 8 expendable) for NP2-13, NC2-48, and NP2-14. Two satellites are launched on two-year cycles and one, NC2-48, is launched every year. The combined payload weight is approximately 900 kg (2,000 lb) if the current design is used or approximately 1,800 kg (4,000 lb) if low cost design is used. The Tug could easily accommodate the current design configurations, reducing the number of Shuttle/Tug flights to approximately 15 instead of 31. This would save the payload programs approximately \$150 to \$200 million over the 19-year program. If NC2-48 were designed for a two-year life rather than one year, further flight reductions could be achieved amounting to seven Shuttle flights and two expendable launch vehicles for an additional savings of \$70 to \$80 million. One multiple payload operation every two years would deploy and retrieve the three payloads of interest, eliminating single payload operations.

The final conditions evaluated were for sun synchronous orbits with plane change maneuvers. The initial orbit is 185 km (100 nmi) circular at 98°. Coplanar transfer to 926 km (500 nmi) is performed by the Tug for NC2-38 (earth observation) or NC2-42 (earth resource) satellites. A subsequent transfer is then made to an inclination of 99.2 degrees at the same altitude, 926 km (500 nmi), to service the polar orbiting NEO-16 earth resources satellite. The Tug then returns to 185 km (100 nmi) at 98 degrees inclination to rendezvous with the Shuttle. These satellites have reasonably compatible launch dates, but some adjustment in schedules would be beneficial. Unfortunately, the nodal regression is relatively low, and after the initial deployment servicing could only be employed for the next 180 days. After this time the orbit planes have regressed to the point that the next

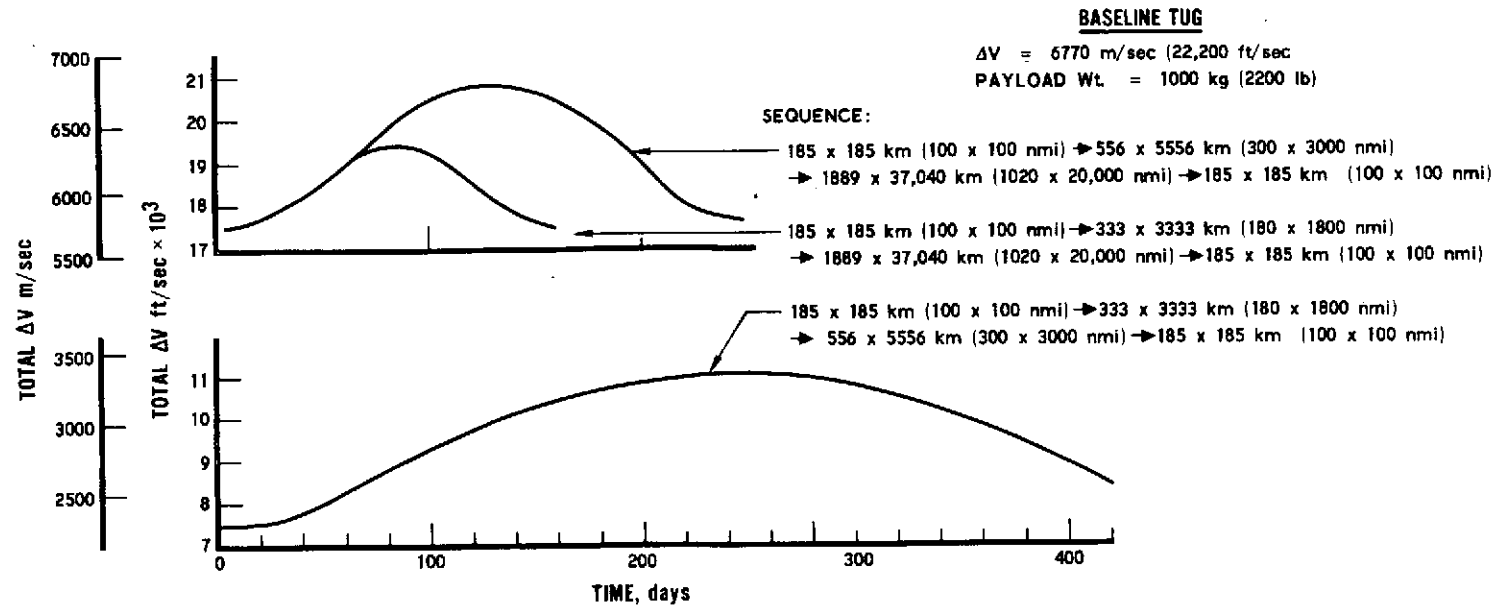


Figure 5-15. Velocity Requirements to Service Two Elliptical 90-deg Orbits

NOTE:

- NEARLY UNRESTRICTED  
SERVICING EXISTS

SEQUENCE:

TRANSFER UP: TO 185 x 185 km (100 x 100 nmi)  
 TO 333 x 3333 km (180 x 1800 nmi)  
 TO 556 x 5556 km (300 x 3000 nmi)  
 TO 1889 x 37,040 km (1020 x 20,000 nmi)  
 TRANSFER DOWN: TO 185 x 185 km (100 x 100 nmi)

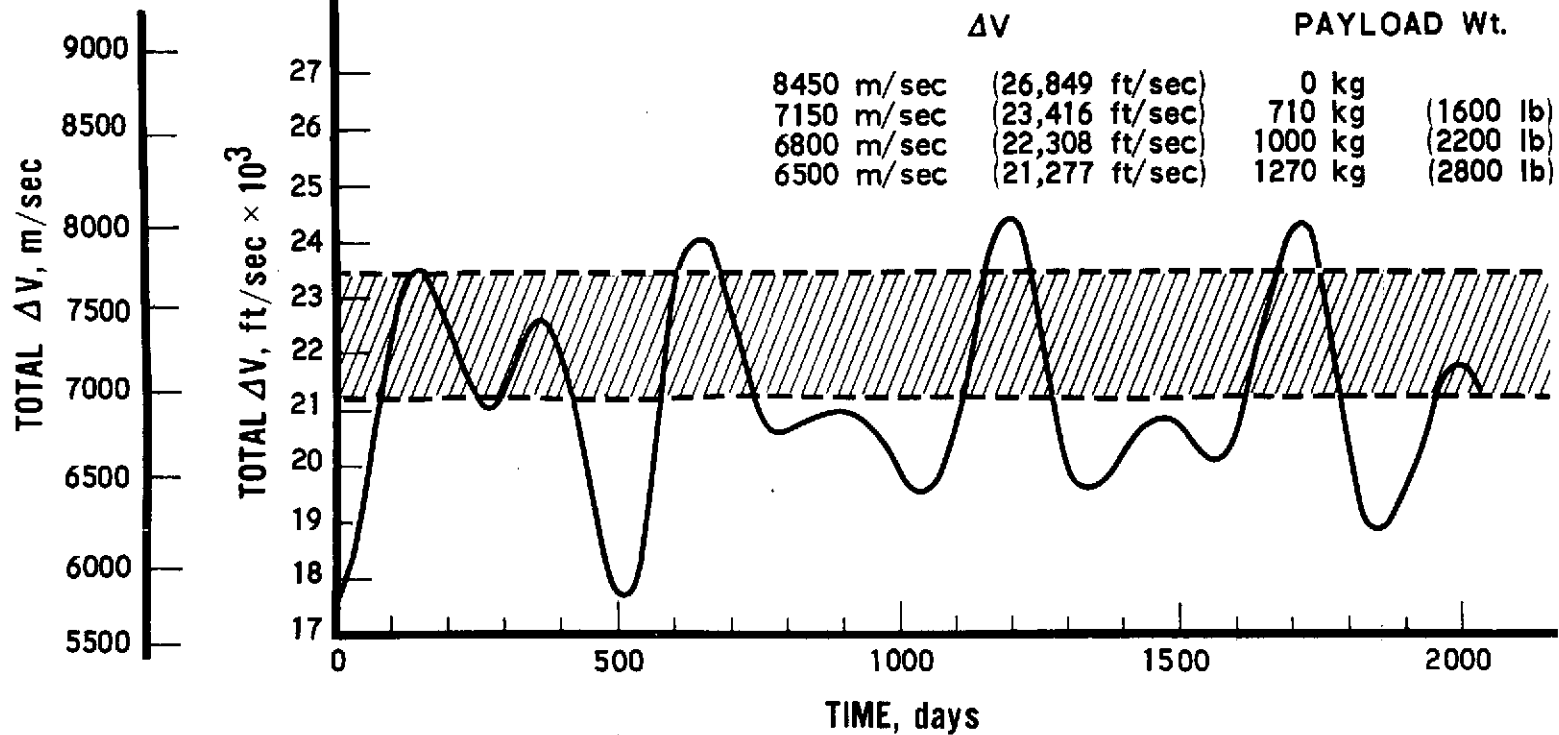


Figure 5-16. Payload Capabilities of Off-Loaded Tug for Servicing Three Elliptical 90-deg Orbits

service opportunity does not occur for another six years. Therefore, these missions are not viable candidates for multiple service or retrieval operations, although they could be deployed simultaneously.

Another set of conditions was then investigated starting with the Tug at 185 km (100 nmi) with an inclination of 99.2 degrees. The Tug transfers to 926 km (500 nmi), circularizes, and then transfers to an orbit of 100.9 degrees and 1,296 km (700 nmi). After performing service in this orbit, another transfer is made to an orbit of 103 degrees at 1,678 km (906 nmi). The maximum velocity increment to service all three orbits is only 2,800 mps (9,200 fps), (well within the Tug capability) over a 10-year period. Therefore, servicing can be performed at any time. The applicable payloads are the earth resources satellite NEO-16 and two meteorological satellites, NEO-7 and NE2-40. Tiros, NE2-40, is scheduled for only one launch in 1981 with no subsequent operations. Since this is before the IOC of the Tug at WTR, there is no present requirement for three-orbit servicing. However, since the mission model is subject to change, it was desirable to evaluate this condition as a worse case.

These results are summarized in Table 5-4, indicating which combinations are compatible with service operations. The low inclination orbits do not provide any substantial opportunity except for synchronous missions. However, if a synchronous mission is required, there is a potential capability to also service low earth orbit payloads, depending upon the total requirements at synchronous orbit. The unique elliptical orbits at 90 degrees inclination are prime candidates for multiple operations. Also, the group of missions at higher inclinations should employ multiple operations. In the previous analysis of Case 403 and Case 506, all of these orbits were treated as unique conditions with dedicated logistic operations. The potential savings to each of these programs, where applicable, is approximately a 60% reduction in launch costs.

One final effort was performed to provide data for future trade-offs. The performance capability of the baseline Tug was assessed against multiple satellite servicing in a synchronous equatorial orbit. Satellites are assumed to be equally distributed over a defined region in this orbit. The

FOLDOUT FRAME

FOLDOUT FRAME

2

Table 5-4. Tug Payload Capabilities

Orbit Inclination	Initial and Final Orbit, km (nmi)	Payload Serviced Altitude, km (nmi)			Launch Window (Days)	(Unavail. (Days)	Operations	
		1	2	3			Service	Payload kg (lb)
28.5° ↓	278 (150) ↓	463 (250) ↓ 551 (297) ↓ 556 (300) 463 (250)	551 (297) 611 (330) 741 (400) 611 (330) 741 (400) 741 (400) 611 (330)	--- --- --- --- --- 400	546 325 183 883 275 417 15	668 400 220 980 330 493 2,800	No No No No No No No	726 (1,600) ↓
28.5°	278 (150)	35,786-0° (19,323)	35,786-29° (19,323)	---	∞	-0-	Yes	340 (750)
55°	185 (100)	500 (270)	12,800 (6,900)	---	23	61	Yes	726 (1,600)
90° ↓	185 (100) ↓	333 × 3,333 (180 × 1,800) 333 × 3,333 (180 × 1,800) 556 × 5,556 (300 × 3,000) 333 × 3,333 (180 × 1,800)	556 × 5,556 (300 × 3,000) 1,889 × 37,040 (1,020 × 20,000) 1,889 × 37,040 (1,020 × 20,000) 556 × 5,556 (300 × 3,000)	--- --- --- 1,889 × 37,040 (1,020 × 20,000)	∞ ∞ ∞ 500	-0- -0- -0- 90	Yes Yes Yes Yes	1,000 (2,200) ↓ 726 (1,600)
98° 99.2°	185 (100)	926 × 926 (500 × 500) →	926 × 926 (500 × 500)		375	6 Years	No	---
99.2° 100.9° 103°	185 (100)	926 × 926 (500 × 500) →	1,296 (700) →	1,678 (906)	∞	-0-	Yes	726 (1,000)

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region of interest varies from 45 degrees total included angle to a full 360 degrees. The effect on payload servicing capability is shown as a function of the number of satellites to be visited in Figure 5-17. This set of data is applicable to a Tug operational time limit of seven days. Figure 5-18 provides the same data for a time limit of 14 days and Figure 5-19 provides data for a 21-day limit.

The improvement in servicing capability is obvious as the total phase angle is reduced and the allowable time on orbit increased. For angles less than 45 degrees there is minimal impact on the Tug capability. Extending the time on orbit lowers the Tug capability by approximately 11 kg (25 lb) of payload per day beyond the seven-day design constraint. These additional losses are due to boiloff and attitude control requirement. However, this effect is more than compensated by the reduced phasing velocity requirements associated with increasing the available time for transfers. For example, the Tug has zero payload capability for servicing five satellites equally placed over 360 degrees in seven days. If 14 days were allowed, the servicing capability would increase to over 726 kg (1,600 lb). If 21 days were allowed, this capability increases to 862 kg (1,900 lb), a substantial improvement over the seven-day constraint.

These data will be employed in future space servicing trade-offs. Reference 9 has already shown that the distribution of satellites at synchronous altitude will be in clusters. Approximately 40% will be over the Continental United States ( $95^{\circ}$  included phase angle) and 20% will be over the European Continent ( $120^{\circ}$  included angle). Twenty percent will be over the Atlantic Ocean and Africa ( $90^{\circ}$  angle) and the remainder over the Pacific, except for approximately 5% which will be randomly placed. The random flights are primarily explorer type missions which probably will not be serviced in any event.

The final objective is to determine if an efficient servicing policy can be established which restricts servicing to specific regions. These data provide the necessary input to support the subsequent analysis.

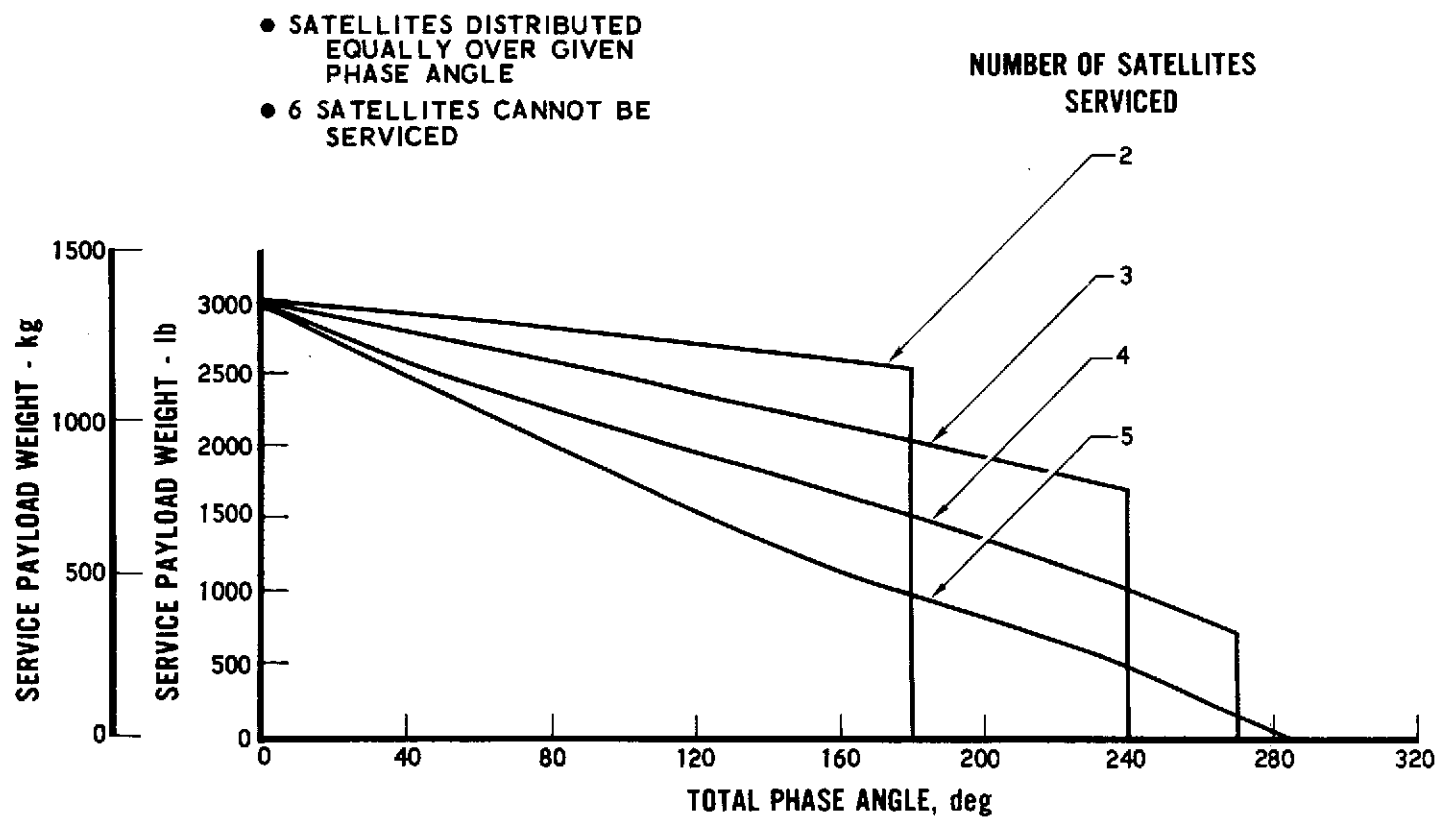


Figure 5-17. Tug Service Capabilities for 7-Day Operating Period



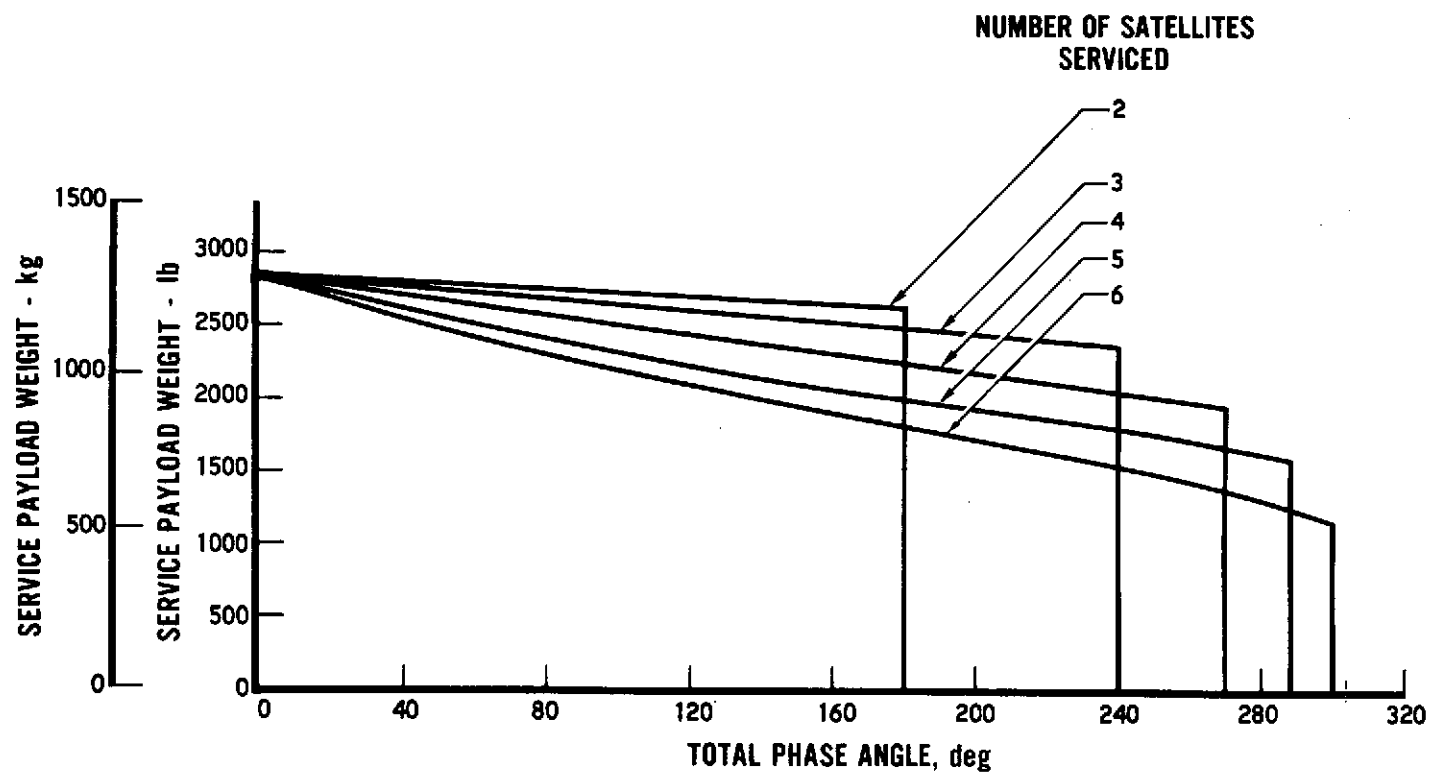


Figure 5-18. Tug Service Capabilities for 14-Day Operating Period

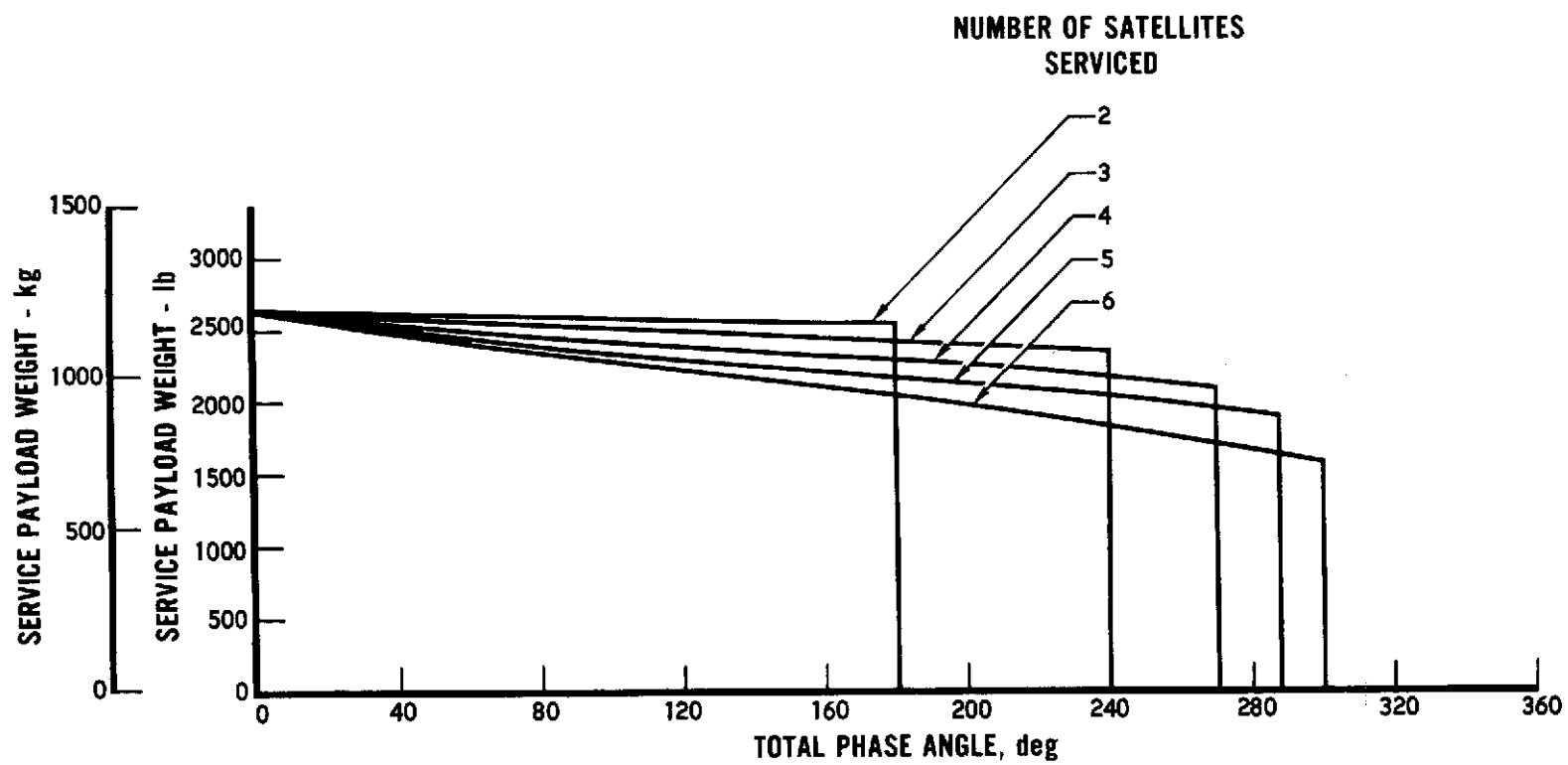


Figure 5-19. Tug Service Capabilities for 21-Day Operating Period

## 6. CONCLUSIONS

The results of this analysis have shown several possible means of improving the overall utilization of resources. These results are based upon the 1971 Baseline Mission Model, and the 1972 excursion. In summary, there are numerous missions in which a very high load factor has been achieved; consequently, further improvement here is questionable. However, there are still a large number of missions with relatively poor load factors. It should be possible through multiple mission operations to improve the overall cost of doing business. In addition, there is a certain degree of inefficiency in utilization of the Tug simply because, for some inclinations, there is insufficient traffic to achieve a reasonable load factor. At the same time, it appears highly desirable to recover and reuse the logistic vehicle, ruling out the use of expendable upper stages. In a few cases, it is also desirable to reexamine the mission requirements leading to specific launch schedules and mission altitudes. A change in these two conditions to allow more efficient operations could have a substantial impact on individual satellite program costs, even if the total adjustment does not influence the overall program costs.

In summary, the following recommendations are made:

1. Continue to examine each grouping in detail to determine if improved load factors can be achieved through multiple payload operations, thereby reducing the overall flight rate.
2. Analyze a shorter Tug configuration relative to its advantages for those specific missions not conducive to multiple operations as well as its application to the total program.
3. Examine, to the extent possible, those payloads which have low load factors due to volumetric constraints to determine if reconfiguration would be beneficial.
4. Analyze on-orbit servicing as an operational concept employing the baseline vehicle definitions and allowing multiple operations to the greatest extent possible.
5. Determine candidate multi-mission platforms as an extension of the on-orbit servicing as a means of reducing overall costs.

6. Determine the benefits of a solar electric orbit transfer vehicle relative to on-orbit servicing of payloads for both individual and multi-mission satellites.

Section 7 describes a recommended study approach for addressing each of these recommendations.

## 7. RECOMMENDED STUDY APPROACH

In reviewing the results of the mission characterization as well as considering current efforts of on-orbit servicing, it is recommended that the following tasks be performed. These, in essence, represent a preliminary set of "Key Issues" as identified in the study plan. The first set of tasks relate to improving the current ground refurbishment type of operations employed in Case 403 and Case 506. The second set of tasks represents the bulk of the effort. It is the intent of this effort to arrive at a statistical assessment of on-orbit servicing versus ground refurbishment/reflight of the mission payloads.

The benefits of a statistical approach should reduce the sensitivity of any conclusions to future changes in the mission model. This should also help compensate for uncertainties in payload and logistic vehicle definitions. In the event the results become obscure, it will be possible to revert to a deterministic solution and perform parametric analyses. A trial case would be performed first to assure the trade-off technique is valid.

### A. GROUND SERVICE TRADE-OFFS

Two trade-offs are recommended for improving ground refurbishment operations:

1. Perform a Tug sizing trade-off with two Tug sizes to determine if the loading efficiency can be improved. If sufficient information exists, reassess the phased development of the Tug from a low technology Tug growing to the baseline at some later date. Consideration should also be given to a storable Tug for comparison.
2. Perform a trade-off regarding the use of a solar electric propulsion stage versus a Tug relative to synchronous equatorial servicing of payloads. If this proves favorable, apply the same trade-off to other mission applications.

### B. ON-ORBIT SERVICE TRADE-OFFS

The fundamental objective is to perform a trade study of on-orbit servicing versus ground servicing assuming a baseline set of logistic vehicles. The following two main approaches should be undertaken and a

multi-mission concept evaluated.

1. Mission Model Reassessment

The June 1972 or subsequent mission models should be reassessed for up/down traffic of payloads. Instead of previous fixed mean mission durations dictating the launch schedule, new values should be developed based upon space-replaceable units. Each mission would be defined in terms of a mission life. This is the operational period in which the satellite system (one or more satellites) should be available to a user. Also, a matrix of candidate modules should be defined using what data are available from the LMSC standardized modules.

Using ground rules agrees to by the NASA Task Monitor, the modules then would be applied to all the payloads in the inventory. The delivery and servicing of the satellites could then be determined and a total program cost developed. Variations in the ground rules and assumptions would be performed to determine a reasonable minimum. This would then be compared with ground servicing relative to total and individual satellite programs.

2. Module Design Data

Since much of the input data developed in Subsection B.1 above will be based on judgment, a second effort will be initiated to develop definitized data. The Defense Support Program (DSP) payload can serve as one data point for modular design. Another satellite (NASA earth observatory satellite) will be selected and a preliminary design for modularization will be performed. Using these two data points, it will then be possible to redevelop the module matrix, assigning a reliability factor for each module. These modules can then be applied to each mission program. A Monte Carlo technique can be applied to vary the reliability of the modules relative to the impact on flight rates, satellite costs, and overall program costs. This then provides a statistical basis for judging the merits of on-orbit servicing.

3.        Multi-Mission Satellites

Multi-mission satellites should be considered as another option. This appears particularly attractive for low earth orbits where orbit regressions preclude or restrict multi-mission operations due to the high velocity requirements for plane changes and phasing. The modular approach of Subsection B.1 would be employed to analyze the merits of this operational concept to the extent that time permits in this contract period.

## 8. REFERENCES

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2. Study 2.6, Operations Analysis Study Plan presented to NASA Task Monitor, October 1972.
3. Integrated Operations/Payloads/Fleet Analysis Final Report, ATR-72(7231)-1, Vols I through VI, The Aerospace Corporation (August 1971).
4. June 1972 Mission Model distributed by NASA.
5. Space Shuttle Mission and Payload Capture Analysis (Study 2.1), The Aerospace Corporation ATR-73(7311)-1, 15 June 1973.
6. "Space Shuttle Performance Capabilities," Revision 1, MSC Internal Note No. 71-FM-350 (16 May 1972).
7. Baseline Tug Definition Document, Revision A, MSFC Report (26 June 1972)
8. Aerospace Study 2.1, Space Shuttle Mission and Payload Capture Analysis, Briefing Material, FY 1972.
9. Geosynchronous Platform Definition Study, NASA Contract NASA-12909, Space Division, Rockwell International (April 1973).



APPENDIX A

NASA MISSION DEFINITIONS--CASE 403 BEST MIX  
(1971 MISSION MODEL)  
(UPPER STAGE LEGS ONLY)

CD

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Tug Deployment/Retrieval Requirements  
1971 Mission Model--"403 Best Mix"

Leg *	Payload	Unit Values		Total Up Values		Total Down Values	
		Weight kg (lb)	Vol. ** m (ft)	No. Up	Weight kg (lb)	No. Dn.	Weight kg (lb)
EØ-0/19.3	NAS 14 BCR	491 (1,083)	1.2 (4)	13	6,386 (14,079)	10	4,912 (10,830)
	NEØ 3 LCR	1,289 (2,841)	3.4 (11)	9	11,598 (25,569)	6	7,732 (17,046)
	NEØ 4 LCR	1,310 (2,889)	3.4 (11)	12	15,725 (34,668)	8	10,483 (23,112)
	NEØ 8 LCE	1,211 (2,670)	3.0 (10)	4	4,844 (10,680)	-	-
	NCN 1 CR	4,320 (9,524)	7.3 (24)	11	47,521 (104,764)	8	34,560 (76,192)
	NCN 2A LCR	584 (1,287)	4.0 (13)	19	11,092 (24,453)	13	7,589 (16,731)
	NCN 3A LCE	852 (1,878)	3.7 (12)	3	2,556 (5,634)	-	-
	NCN 5 CR	1,269 (2,797)	4.9 (16)	15	19,031 (41,955)	10	12,687 (27,970)
	NCN 12 CE	1,597 (3,520)	7.6 (25)	2	3,193 (7,040)	-	-
	NCN 13 CR	1,107 (2,440)	4.9 (16)	16	37,631 (82,960)	26	28,776 (63,440)
	NEØ 11 CR	564 (1,244)	2.1 (7)	16	9,028 (19,904)	12	6,771 (14,928)
	NEØ 15 CR	567 (1,250)	2.7 (9)	19	10,773 (23,750)	13	7,371 (16,250)
	NCN 7 CR	804 (1,773)	7.0 (23)	16	12,867 (28,368)	9	7,238 (15,957)
	NCN 8 CR	1,876 (4,136)	7.6 (25)	33	61,910 (136,488)	22	41,273 (90,992)
	NCN 9 CR	564 (1,244)	4.0 (13)	45	25,392 (55,980)	28	5,800 (34,832)
	NCN 10 BCR	405 (893)	2.7 (9)	15	6,076 (13,395)	8	3,241 (7,144)
	TOTALS			266	285,626 (629,687)	173	188,436 (415,424)
EØ-28/38.6	NAS 11 CE	4,695 (10,350)	7.6 (25)	2	9,390 (20,700)		
EØ-28/1.8	NSP 1A LCR	2,140 (4,718)	4.0 (13)	10	21,401 (47,180)	7	14,981 (33,026)

\* Leg nomenclature corresponds to DORCA input; for reference, see Tables 3-2 and 3-11.

\*\* Volume factor; i. e. , length occupied in 4.57m x 18.29m (15ft x 60 ft) payload bay.

Tug Deployment/Retrieval Requirements (Continued)

1971 Mission Model--"403 Best Mix"

Leg	Payload	Unit Values		Total Up Values		Total Down Values	
		Weight kg (lb)	Vol. m (ft)	No. Up	Weight kg (lb)	No. Dn.	Weight kg (lb)
EØ9-90/1.8	NSP 1 BLCR	2,140 (4,718)	4.0 (13)	9	19,260 (42,462)	6	12,841 (28,308)
EØ9-90/20	NSP 2 BLCR	1,223 (2,698)	3.0 (10)	9	11,014 (24,282)	6	7,343 (16,188)
EØ1-100/0.7	NEØ 6 CR	564 (1,244)	3.4 (11)	5	2,821 (6,220)	4	2,257 (4,976)
	NEØ 7 CR	564 (1,244)	2.1 (7)	19	10,721 (23,636)	13	7,336 (16,172)
	TOTALS			24	13,543 (29,856)	17	9,593 (21,148)
EØ-29/30	NCN 10 ACR	405 (893)	2.7 (9)	10	4,051 (8,930)	7	2,835 (6,251)
EØ-30/19.3	NAS 7 CE	853 (1,880)	3.7 (12)	3	2,558 (5,640)	-	-
	NAS 9 CE	1,424 (3,140)	3.0 (10)	1	1,424 (3,140)	-	-
	NAS 10 CE	1,424 (3,140)	3.0 (10)	1	1,424 (3,140)	-	-
	TOTALS			5	5,407 (11,920)		
EØ-P40	NPL 1 CE	3,502 (7,720)	3.7 (12)	3	10,505 (23,160)	-	-
	NPL 19 CE	4,808 (10,600)	4.9 (16)	3	14,424 (31,800)	-	-
	NPL 20 CE	5,171 (11,400)	7.0 (23)	3	15,513 (34,200)	-	-
	TOTALS			9	40,442 (89,160)		
EØ9-90/3	NCN 3 BLCR	916 (2,020)	4.0 (13)	3	2,749 (6,060)	3	2,749 (6,060)
	NCN 2 BLCR	584 (1,287)	4.0 (13)	19	11,092 (24,453)	13	7,589 (16,731)
	TOTALS			22	13,841 (30,513)	16	10,338 (22,791)
EØ-28/20	NSP 2A LCR	1,224 (2,698)	3.0 (10)	10	12,238 (26,980)	7	8,567 (18,886)

Tug Deployment/Retrieval Requirements (Continued)

1971 Mission Model--"403 Best Mix"

Leg	Payload	Unit Values		Total Up Values		Total Down Values	
		Weight kg (lb)	Vol. m (ft)	No. Up	Weight kg (lb)	No. Dn.	Weight kg (lb)
EØ-28/8-7	NAS 8 CE	1,143 (2,520)	3.7 (12)	3	13,717 (30,240)	-	-
	NSP 3 LCE	544 (1,200)	2.4 (8)	19	4,355 (9,600)	-	-
	NSP 7 LCE	517 (1,140)	2.4 (8)	3	4,137 (9,120)	-	-
	TOTALS			25	22,208 (48,960)		
EØ-P39	NPL 5 LCE	1,080 (2,380)	3.7 (12)	1	1,080 (2,380)	-	-
	NPL 6 CE	3,583 (7,900)	3.7 (12)	2	7,167 (15,800)	-	-
	NPL 7 LCE	4,898 (10,800)	9.1 (30)	1	4,899 (10,800)	-	-
	NPL 8 LCE	2,899 (6,390)	9.1 (30)	2	5,797 (12,780)	-	-
	TOTALS			6	18,942 (41,760)	-	-
EØ-P53.5	NPL 14 CE	1,678 (3,700)	4.6 (15)	3	5,035 (11,100)	-	-
EØ-P51.5	NPL 11 CE	422 (930)	4.6 (15)	4	1,687 (3,720)	-	-
	NPL 13 CE	1,492 (3,290)	4.6 (15)	3	4,477 (9,870)	-	-
	TOTALS			7	6,164 (13,590)		
EØ-P2.4-8	NPL 15 CE	862 (1,900)	6.1 (20)	2	1,724 (3,800)	-	-
	NPL 18 CE	939 (2,070)	6.1 (20)	4	3,756 (8,280)	-	-
	TOTALS			6	3,756 (12,080)		
GRAND TOTALS				423	494,043(1,089,160)	239	254,933 (562,022)

## APPENDIX B

NASA MISSION DEFINITIONS--CASE 506 BEST MIX  
(1972 JUNE MISSION MODEL)  
(UPPER STAGE LEGS ONLY)

Tug Deployment/Retrieval Requirements  
1972 Mission Model--"506 Best Mix"

Leg *	Payload	Unit Values		No. Up	Total Up Values	No. Dn.	Total Down Values
		Weight kg (lb)	Vol. ** m (ft)		Weight kg (lb)		Weight kg (lb)
EØ-0/19.3	NE 39 LCR	2,511 (5,536)	3.6 (11.7)	8	20,089 (44,288)	5	12,556 (27,680)
	NE 41 CE	270 (596)	2.4 (8)	4	1,081 (2,384)	-	-
	NE 43 LCR	1,798 (3,964)	3.4 (11.3)	4	7,192 (15,856)	3	5,394 (11,892)
	NC 46 LCR	2,900 (6,394)	6.2 (20.2)	10	29,003 (63,940)	-	-
	NC 47 LCR	374 (824)	3.0 (9.9)	19	7,102 (15,656)	13	4,859 (10,712)
	NC 49 CR	994 (2,191)	3.0 (10)	9	8,945 (19,719)	6	5,963 (13,146)
	NC 50 LCR	1,515 (3,339)	4.6 (15.2)	1	1,515 (3,339)	-	-
	NC 51 LCR	1,896 (4,181)	4.6 (15.1)	14	26,551 (58,534)	5	9,482 (20,905)
	NCN 7 CR	800 (1,764)	2.9 (9.6)	16	12,802 (28,224)	12	9,602 (21,168)
	NCN 8 CR	1,796 (3,959)	7.6 (25)	33	59,261 (130,647)	23	41,303 (91,057)
	NCN 9 LCR	925 (2,040)	3.4 (11.1)	45	41,640 (91,800)	34	31,461 (69,360)
	NCN 10 BLCR	784 (1,729)	3.4 (11.1)	10	7,843 (17,290)	8	6,274 (13,832)
	NEØ 15 LCR	1,151 (2,537)	3.5 (11.6)	19	21,864 (48,203)	15	17,262 (38,055)
	NEØ 11 LCR	914 (2,013)	3.4 (11.1)	16	14,609 (32,208)	8	7,305 (16,104)
	TOTALS			208	259,499 (572,088)	132	151,462 (333,911)
EØ-28/38.6	NA 11 LCR	2,156 (4,752)	7.2 (23.7)	2	4,311 (9,504)	1	2,156 (4,752)
EØ-P47.8	NP 17 LCE	665 (1,467)	3.7 (12.1)	3	1,996 (4,401)	-	-

\* Leg nomenclature corresponds to DORCA input; for reference, see Tables 3-2 and 3-11.

\*\* Volume factor; i.e., length occupied in 4.57m × 18.29m (15ft × 60ft) payload bay.

Tug Deployment/Retrieval Requirements (Continued)

1972 Mission Model--"506 Best Mix"

Leg	Payload	Unit Values		No. Up	Total Up Values	No. Dn.	Total Down Values
		Weight kg (lb)	Vol. m (ft)		Weight kg (lb)		Weight kg (lb)
EØ9-90/1.8	NP 13 LCR	870 (1,918)	3.1 (10.4)	10	8,700 (19,180)	4	3,480 (7,672)
EØ9-90/20	NP 14 LCR	442 (974)	3.2 (10.6)	10	4,418 (9,740)	8	3,534 (7,792)
EØ4-100/0.7	NEØ 7 LCR	906 (1,998)	3.4 (11.2)	19	17,220 (37,962)	15	13,594 (29,970)
EØ-28/30	NCN 10 ALCR	784 (1,729)	3.4 (11.1)	15	11,764 (25,935)	9	7,058 (15,561)
EØ-28/19.3	NA 2 LCR	358 (789)	4.4 (14.3)	5	1,789 (3,945)	2	716 (1,578)
EØ-P40	NP 15 LCE	603 (1,330)	3.2 (10.6)	9	5,430 (11,970)	-	-
EØ9-90/3	NC 48 LCR	374 (824)	3.0 (9.9)	15	5,606 (12,360)	9	3,364 (7,416)
EØ4-100/0.5	NE 38 LCR	1,854 (4,088)	3.4 (11.1)	11	20,397 (44,968)	5	9,272 (20,440)
	NE 42 LCR	1,462 (3,223)	3.4 (11)	12	17,543 (38,676)	4	5,848 (12,892)
	NEØ 16 LCR	2,113 (4,658)	3.4 (11.2)	34	71,839 (158,372)	20	42,257 (93,160)
	TOTALS			57	109,778 (242,016)	29	57,377 (126,492)
EØ5-55/6.9	NP 18 LCR	4,144 (9,136)	7.6 (25)	4	16,576 (36,544)	2	8,288 (18,272)
EØ-P54.5	NP 20 LCE	452 (996)	4.0 (13)	2	904 (1,992)	-	-
EØ-P37.9	NU 22 LCE	5,413 (11,933)	5.4 (17.8)	4	41,610 (91,732)	-	-
	NU 23 LCE	3,626 (7,993)	4.9 (16.1)	2	7,251 (15,986)	-	-
	TOTALS			6	48,860 (107,718)		
EØ-P42.3	NU 27 CE	2,390 (5,269)	7.6 (25)	2	4,780 (10,538)	-	-
EØ-P51.2	NU 29 LCE	1,079 (2,379)	3.5 (11.4)	4	4,316 (9,516)	-	-

Tug Deployment/Retrieval Requirements (Continued)

1972 Mission Model--"506 Best Mix"

Leg	Payload	Unit Values		No. Up	Total Up Values	No. Dn.	Total Down Values
		Weight kg (lb)	Vol. m (ft)		Weight kg (lb)		Weight kg (lb)
EØ-P49.9	NU 30 LCE	645 (1,424)	4.4 (14.3)	4	2,584 (5,696)	-	-
EØ-P48.3	NU 31 LCE	705 (1,554)	4.5 (14.6)	4	2,820 (6,216)	-	-
EØ-P57.4	NU 33 LCE	3,000 (6,613)	4.9 (16)	4	11,999 (26,452)	-	-
EØ-P50.8	NU 34 LCE	2,172 (4,788)	7.6 (25)	3	6,516 (14,364)	-	-
EØ-P36.5	NU 37 LCE	2,575 (5,677)	4.6 (15.2)	2	5,150 (11,354)	-	-
EØ-P38.5	NU 24 LCE	787 (1,734)	4.2 (13.9)	2	1,573 (3,468)	-	-
	NU 25 LCE	1,508 (3,325)	3.4 (11.1)	4	6,033 (13,300)	-	-
	NU 26 LCE	843 (1,859)	3.5 (11.6)	4	3,373 (7,436)	-	-
	TOTALS			10	10,979 (24,204)		
EØ-P49.4	NU 28 LCE	1,594 (3,514)	5.5 (17.9)	2	3,188 (7,028)	-	-
	NU 32 LCE	1,641 (3,617)	4.9 (16.1)	3	4,922 (10,851)	-	-
	TOTALS			5	8,110 (17,879)		
EØ-P47.5	NU 35 LCE	2,037 (4,490)	5.2 (17)	2	4,073 (8,980)	-	-
	NU 36 LCE	1,970 (4,342)	4.0 (13.2)	4	7,878 (17,368)	-	-
	TOTALS			6	11,951 (26,348)		
GRAND TOTALS				409	566,057(1,247,922)	211	251,029 (553,416)